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MAIN DRAINAGE WORKS

OF

BOSTON

AND ITS

METROPOLITAN SEWERAGE DISTRICT

COMPLIMENTS OF

METROPOLITAN SEWERAGE COMMISSIONERS.

HOSEA KINGMAN,
TILLY HAYNES,
GEORGE A. KIMBALL,
Commissioners.

WILLIAM M. BROWN, Jr.,
Chief Engineer and Superintendent.

HERBERT E. BRAYTON,
Clerk.

9/FEB 6 1900

BOSTON:
WRIGHT & POTTER PRINTING CO., STATE PRINTERS,
18 POST OFFICE SQUARE.
1899.

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OF

BOSTON

AND ITS

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PUBLISHED UNDER THE AUTHORITY OF THE METROPOLITAN SEWERAGE
COMMISSIONERS, BOSTON, MASSACHUSETTS, U. S. A.

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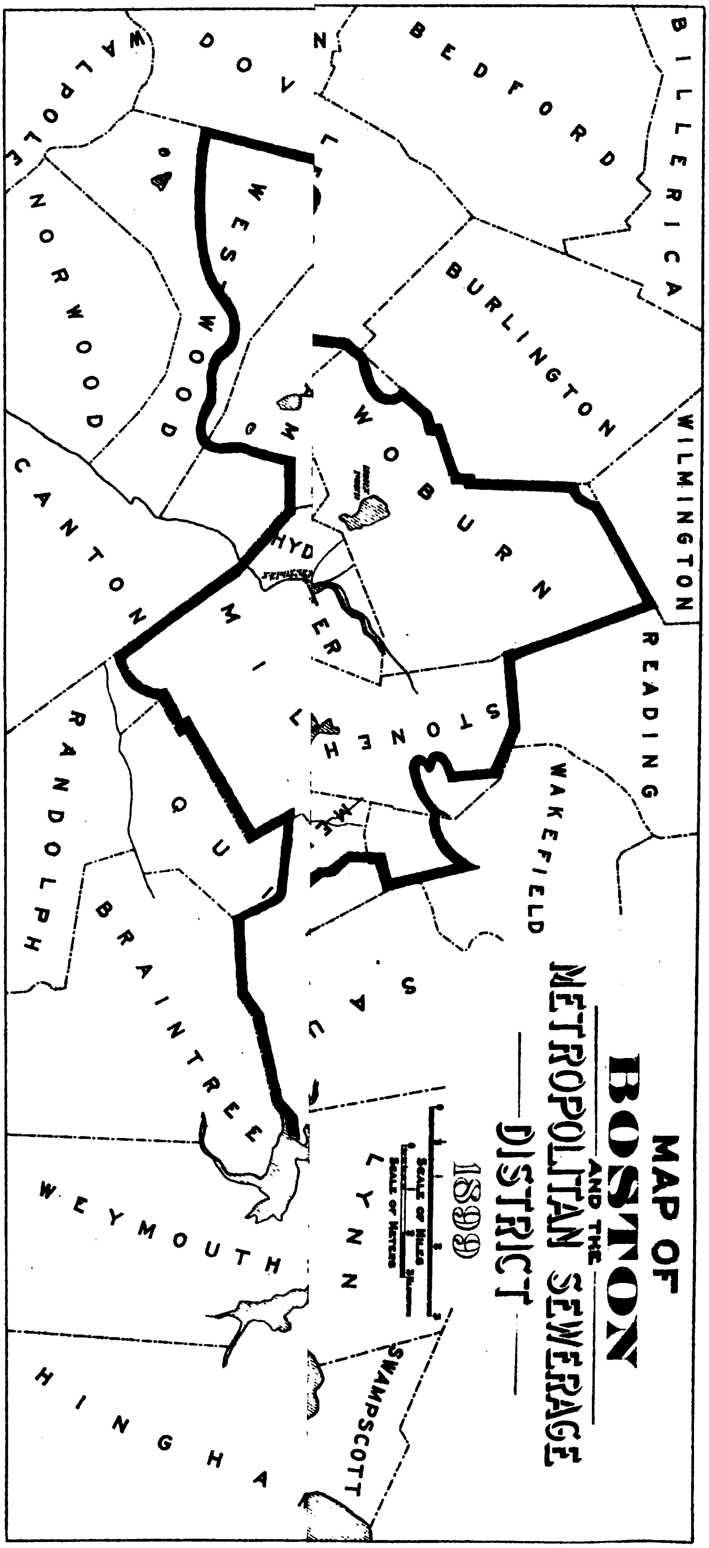

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MAIN DRAINAGE WORKS OF BOSTON AND ITS METROPOLITAN SEWERAGE DISTRICT.

Boston, the capital city of the Commonwealth of Massachusetts, has an area of about 38 square miles. The Mystic, Charles and Neponset rivers, all of considerable magnitude, intersect or limit this city area and discharge into Boston harbor.

The original land surface forming the city proper is of very limited extent. The large increase is due, in part, to extensive reclamations from the adjacent marshes and tidal flats, but chiefly to successive assimilations of neighboring territory. The population of the city in 1895, as recorded by the semi-decennial State census of that year, was 496,920, and its present estimated population of 541,000 (October 1, 1899) places it in the fifth rank in this respect among the great cities of the United States. The total assessed valuation of real and personal estate, as prepared by the Tax Commissioner under the provisions of sections 96 and 97 of chapter 11 of the Public Statutes, and recorded in chapter 232 of the legislative Acts of 1898, amounts to $1,069,723,585.

THE METROPOLITAN SEWERAGE DISTRICT.

The city is bounded on its landward borders by a metropolitan district lying within a radius of 10 miles from the State House, comprising 23 municipalities, with an area of about 161 square miles. The population of these 23 municipalities was enumerated as 400,153 in 1895, and is estimated at 466,847 October 1, 1899. The aggregate valuation of real and personal estate, as prepared by the Tax Commissioner in 1898, was $514,664,831. The following table shows the foregoing figures in greater detail. Comparing these figures with the corresponding data for the entire Commonwealth, Boston with its metropolitan district includes 2½ per cent. of the area, 36 per cent. of the population, and 55 per cent. of the 1898 assessed valuation.

Table showing Area, Population and Valuation of Boston and its Metropolitan District.

City or Town.	Area. (Square Miles.)	Population according to Semi-decennial State Census of 1895.	Estimated Population, October 1, 1899.	Gross Valuation of Real and Personal Estate, Chap. 232, Acts 1898.
Boston (including the city proper, East Boston, South Boston, Charlestown, Dorchester, Roxbury, West Roxbury and Brighton), ...	38.250	496,920	541,641	$1,069,723,585
Metropolitan district: —				
Arlington, ...	5.196	6,515	7,783	8,976,266
Belmont, ...	4.657	2,843	3,768	4,815,982
Brookline, ...	6.807	16,159	19,391	74,251,728
Cambridge, ...	6.111	81,519	91,264	92,791,563
Chelsea, ...	2.240	31,295	33,779	23,673,450
Dedham,*	14.100	6,630	7,200	8,250,000
Everett, ...	3.340	18,578	24,516	15,065,406
Hyde Park, ...	4.572	11,828	13,646	9,729,118
Lexington,*	5.110	2,478	2,730	3,088,688
Malden, ...	5.074	29,706	36,101	29,849,388
Medford, ...	8.350	14,480	18,176	19,391,980
Melrose, ...	3.730	11,966	14,873	12,693,425
Milton, ...	12.589	5,518	6,624	22,192,943
Newton, ...	18.030	27,622	32,484	59,103,233
Quincy, ...	12.555	20,712	24,862	18,945,036
Somerville, ...	3.965	52,193	61,799	51,475,670
Stoneham, ...	5.495	6,278	6,776	4,945,050
Wakefield,*	.950	654	760	822,763
Waltham, ...	13.632	20,877	23,055	19,627,274
Watertown, ...	4.045	7,788	8,998	10,282,882
Winchester, ...	5.952	6,146	7,149	7,968,162
Winthrop, ...	1.613	4,192	5,558	6,142,687
Woburn, ...	12.705	14,176	15,555	10,582,137
Totals of Boston and its metropolitan district, . .	199.068	897,073	1,008,488	$1,584,388,416

* Part of town.

Unsanitary Conditions. — With the increasing density of population on the areas above defined, the necessity for some satisfactory method of sewage disposal became yearly more urgent. This was especially the case in the city of Boston, where, as early as 1870, an aggregation of old sewers discharged by about seventy outlets into tide water, chiefly along the harbor front. The fluctuations of the tide, particularly in the inner harbor, served to aggravate conditions which were, even without this factor, manifestly inimical to public health and comfort. The numerous complaints received by the city authorities led to the appointment in 1875 of a joint engineering and medical commission, to formulate a remedy for conditions fast becoming dangerous to the public health.

Report of the 1875 Commission. — The report of this commission was very broad in its scope, and included proposals dealing with metropolitan districts north and south of the Charles River.

Two systems of main drainage were recommended, one to intercept the sewage of Boston proper, South Boston, Roxbury, Dorchester, Brookline, Brighton, Newton and other territory between the Charles and Neponset rivers, and to carry it through an intermediary pumping station to an outlet at Moon Island.

The second system was intended to deal in like manner with the sewage of Cambridge, Somerville, Charlestown, Everett, Chelsea, East Boston, Winthrop and other districts north of the Charles River, by a pumping station at Breed's Island and an outlet at Shirley Gut.

BOSTON MAIN DRAINAGE WORKS.

At an early date action was taken on this report by the city, which constructed, from 1877 to 1884, a comprehensive system of sewage disposal works, providing for the area south of the Charles River. The works correspond in their main features with the project proposed and recommended by the commission of 1875, and are known as the Boston main drainage works. They comprise 25 miles of main and intercepting sewers, ranging from 2½ feet to 10½ feet in diameter, located generally along the tidal margins of the city and lying mainly below the level of low tide; a pumping station at Old Harbor Point, where the sewage is lifted about 35 feet through force mains into twin deposit sewers, in which heavy matters settle before the sewage reaches a tunnel crossing under Dorchester Bay; an outfall sewer built on an embankment leading from the tunnel to the Moon Island reservoir, where the sewage is stored during the latter half of the ebb tide and the whole of the flood tide; and discharge channels leading to the tidal currents in the harbor. The principal features of these works are indicated on the general map herewith.

Pumping Station. — Before being admitted to the pumps the sewage is passed through screens, consisting of iron cages working in vertical shafts and operated by special machinery. The station contains two high-duty compound pumping engines, having a nominal capacity of 25,000,000 gallons per day each, and two low-duty engines, of the same nominal capacity, for use when the volume of sewage is increased by rain. The engines have dimensions, etc., as follows: —

High-duty Engines.

Diameter of high-pressure cylinder,	25½ inches.
Diameter of low-pressure cylinder,	52 inches.
Diameter of plunger,	48 inches.
Length of stroke,	9 feet.
Diameter of fly-wheel,	36 feet.
Weight of fly-wheel,	36 tons.
Speed for nominal capacity (revolutions),	11 per minute.
Duty by test (foot-pounds per 100 pounds coal),	122,000,000.

Low-duty Engines.

Diameter of high-pressure cylinder,	21 inches.
Diameter of low-pressure cylinder,	36 inches.
Diameter of plunger,	45 inches.
Length of stroke,	4 feet.
Speed for nominal capacity (double strokes),	12 per minute.
Guaranteed duty (foot-pounds per 100 pounds coal),	60,000,000.

Deposit Sewers. — Two sewers, 8 feet wide and 16 feet high, run side by side for a distance of 1,260 feet, terminating in each case with a dam, which keeps the sewage at a sufficiently high level to ensure a current velocity not exceeding 1 foot per second, thus favoring deposit. The deposits are moved by a travelling scraping and flushing machine, operated by the current, and are delivered through pipes to a sludge tank, from which the liquid sewage flows back into the west shaft, at the end of the deposit sewers. The sludge removed from the tank is discharged into scows and towed out to sea. The amount of sludge thus handled in 1898 amounted to 8,670 cubic yards.

Dorchester Bay Tunnel.

Total length,	7,160 feet.
Inside diameter of brickwork,	7½ feet.
Thickness of brick lining,	12 inches.
Depth below low tide,	143 feet.
Ordinary velocity of sewage flow,	2 feet per second.
Velocity with four pumps running,	4 feet per second.

Outfall Sewer. — The outfall sewer from the tunnel to the reservoir is of the horse-shoe cross-section, 11 feet high and 12 feet wide, with a total length of 5,900 feet.

Reservoir. — The masonry reservoir covers an area of 5 acres, and has a capacity of from 22,000,000 to 25,000,000 gallons, according to the depth of sewage. Works are now in progress which will nearly double the area and capacity. The reservoir is divided by longitudinal walls into four sections, each of which can be isolated from the rest for cleaning and repairs. The floor is of concrete, finished with alternating ridges and gutters, in brickwork, at a mean elevation of 1 foot below high water.

Method of Disposal. — The sewage is stored in the reservoirs so as to admit of its discharge for one and one-half to two hours during the first half of each ebb tide. Being lighter than the salt water, it rises to the surface, and at the end of half an hour after the discharge covers an area of half a mile in diameter. This can be plainly seen by its color, and also because it contains sufficient grease to still the waves. At the end of another hour it is so far diluted that no trace of it is visible, and chemical analysis of the water which has received the sewage shows that by the time it has travelled two miles below the outlet it is but little more polluted than the water which has not come into contact with the sewage, and even less than the water in the harbor near the city.

Included Area. — The territory which it was expected would eventually be tributary to these works is bounded by Charles River, Boston harbor, Neponset River and Mother

Brook. It comprises about 58 square miles. The lower portion of this territory, not more than 40 feet above mean low water, and comprising about 12 square miles, was expected to be always tributary to the low-level intercepting sewers, and thus the sewage from this area would always need to be pumped. The sewage from the higher portions of this territory, more than 40 feet above mean low water, and comprising about 46 square miles, was expected to be intercepted by a high-level sewer, to be built in the future, which would convey this sewage by gravity to the outfall sewer beyond the pumping station, thus avoiding the necessity for pumping the sewage from these districts. A branch was left in the outfall sewer, to which a high-level sewer might be connected. As it might be some years before a high-level sewer would be built, and as some portions of the higher districts might require sewerage in the mean time, it was thought best to give to the low-level system a capacity sufficient to provide for the sewage from 3 square miles of the higher districts, in addition to the 12 square miles of low districts properly belonging to that system. The capacity of the main sewer at the pumping station was therefore made sufficient to receive the sewage from 15 square miles of territory.

Volume provided for. — The population to be ultimately provided for upon this territory was estimated at 600,000, being an average of 40,000 to each square mile, a density nearly equal to that of the old city proper. The provision for sewage capacity was based upon an average water consumption of 75 gallons per day for each inhabitant, doubled for the maximum rate, or 150 gallons per twenty-four hours per capita. A provision was made for one-quarter of an inch of rain falling upon the area of 15 square miles in twenty-four hours. It was estimated that this really provided for half-an-inch in that time, as not more than half of a light rain would reach the sewers. For convenience in calculations, the rainfall was taken as one one-hundredth of an inch per hour. In all these computations the proposed sewers were assumed as flowing half-full.

Cost of Construction. — The amount expended on the works up to October 1, 1899, is about $6,500,000, which includes the enlargement of the reservoirs and other extensions since the completion of the original works. The funds to meet the cost of construction have been principally raised by the issue of bonds bearing interest at rates varying from 5 to 3½ per cent., and running forty years, a fixed annual amount being set aside as a sinking fund to liquidate the debt in that period.

Maintenance and Operation. — The works have been in continuous operation since 1884. The following table shows the volume of sewage pumped and other items of pumping work during the year ending January 31, 1899: —

BOSTON STREET DEPARTMENT — SEWER DIVISION — PUMPING STATION, DORCHESTER.

Report of Pumping during the Year ending January 31, 1899.

	ENGINE NO. 1.		ENGINE NO. 2.		ENGINE NO. 3.		ENGINE NO. 4.		Total Gallons pumped.	Daily Average Amount pumped (Gallons).	Daily Average Amount of Coal used (Pounds).	Per Cent. of Ashes and Clinkers.	Gallons pumped per Pound of Coal used.	Average Lift (Feet).	Duty in Foot-pounds per 100 Pounds Coal used.	Rainfall (Inches).
	Pumping Time.	Gallons pumped.	Pumping Time.	Gallons pumped.	Pumping Time.	Gallons pumped.	Pumping Time.	Gallons pumped.								
1898.	h. m.		h. m.		h. m.		h. m.									
February, .	517 05	721,951,296	539 18	759,147,253	641 07	931,885,331	652 57	930,276,741	3,343,260,821	119,402,172	41,457	8.1	2,880	35.7	83,952,130	4.28
March, . .	614 50	867,022,826	538 10	752,308,437	729 38	1,025,482,954	615 35	859,398,071	3,504,188,288	113,038,331	43,826	10.6	2,609	36.1	78,023,927	1.25
April, . .	578 10	805,862,229	417 35	572,397,229	657 33	939,845,341	705 15	997,455,986	3,315,560,855	110,518,695	43,876	14.2	2,518	33.8	73,005,844	4.62
May, . .	688 25	969,341,185	471 50	660,641,612	723 52	1,045,640,794	510 20	731,157,850	3,406,781,441	109,896,175	43,870	13.7	2,533	34.9	73,310,190	4.50
June, . .	600 20	829,904,428	3 40	5,162,442	702 55	1,012,064,487	671 55	939,128,161	2,786,259,518	92,875,317	34,815	8.8	2,667	36.3	80,013,114	1.87
July, . .	159 30	219,926,013	420 05	560,090,520	730 25	1,037,218,096	729 00	1,012,153,202	2,829,382,649	91,270,408	32,337	11.8	2,822	36.3	84,664,804	3.40
August, . .	330 10	437,628,368	583 25	759,504,984	719 38	1,028,529,802	327 40	454,128,731	2,679,791,885	86,444,899	33,464	10.9	2,583	35.6	76,575,318	4.24
September, .	511 40	692,615,840	668 10	900,924,440	709 00	1,028,094,536	-	-	2,621,634,816	87,387,827	36,063	12.7	2,423	36.0	70,279,004	1.78
October, .	438 10	571,152,244	682 20	959,307,304	680 20	997,996,970	-	-	2,528,456,518	81,563,113	34,548	11.7	2,361	34.8	66,316,348	6.64
November, .	582 10	785,775,442	700 00	941,500,500	672 03	951,847,352	-	-	2,679,123,294	89,304,109	36,126	13.7	2,472	35.7	73,128,457	4.08
December, .	715 50	954,310,396	716 40	963,944,706	726 58	1,069,292,997	-	-	2,987,548,099	96,372,519	39,780	12.5	2,422	35.4	72,201,370	1.60
1899.																
January, .	723 30	967,998,619	725 45	978,560,783	728 50	1,057,636,827	18 00	21,861,640	3,026,067,869	97,615,092	41,497	12.6	2,352	35.4	69,552,102	4.44
Totals, .	6,457 90	8,823,488,886	6,464 98	8,813,490,280	8,419 79	12,125,540,487	4,229 22	5,945,536,400	35,708,056,053	1,175,688,657	460,659	141.3	30,642	426.0	901,022,608	42.70
Averages,	-	-	-	-	-	-	-	-	-	97,974,054	38,388	11.7	2,553	35.5	75,085,217	-

The total cost of maintenance and operation for the same period, exclusive of interest and sinking fund charges, was about $125,000.

Design of Works. — The works and their extensions, to October 1, 1899, have been designed by successive city engineers of Boston, Mr. Joseph P. Davis, Mr. Henry M. Wightman and Mr. William Jackson. Mr. Eliot C. Clarke was principal assistant engineer in charge of construction until the completion of the works in 1884.

THE METROPOLITAN SEWERAGE SYSTEM.

During the execution of the works described above, increasing attention was directed by the public to the necessity of similar works for the metropolitan district adjoining the city on both sides of the Charles River. The problem was complicated by the difficulty, in many cases amounting to impossibility, of dealing with the sewage of any given area within the borders of the municipality affected. Any sewers constructed for the relief of one such area would necessarily traverse one or more districts under other jurisdiction; and it was finally recognized that no authority, other than that of the Commonwealth, was sufficiently comprehensive to embrace the entire district to be served.

Action by the Legislature. — Successive commissions were appointed to investigate the problem, and to report methods for the relief of the communities affected. The Metropolitan Drainage Commission of 1881 was succeeded by the Massachusetts Drainage Commission of 1884 and 1885. Concurrently with the researches of these bodies the State Board of Health had devoted much study to the general question of sewage disposal; and the Legislature, by chapter 95 of the Acts of 1887, directed this Board to consider and report on a general system of drainage and sewerage for the relief of the Mystic and Charles River valleys, comprising a metropolitan area of about 114 square miles.

Report of the State Board of Health, 1889. — The report recommended the division of the proposed metropolitan district into two parts, dictated by physical and geographical considerations, with an independent harbor outfall for the larger portion, north of the Charles River, designated as the north metropolitan system. In this were then included the isolated Charlestown and East Boston areas of the city of Boston, the cities of Cambridge, Somerville, Malden, Chelsea, Medford,* Everett* and Woburn, and the towns of Stoneham, Melrose, Winchester, Arlington, Belmont and Winthrop. Deer Island light, near the mouth of Boston harbor, was selected as the most suitable point of discharge. The remaining area, known as the Charles River valley district, included Brighton and part of the Back Bay section of Boston, the cities of Waltham and Newton and the towns of Brookline and Watertown. The Board concluded that this district could be effectively provided for by the construction, south of the Charles River, of an intercepting sewer, following the general direction of the river and to be connected with the Boston main drainage system.

Pumping. — The arrangement proposed for the Charles River valley system obviated the necessity for lifting the sewage of that district except at the pumping station of the Boston main drainage works. In the north metropolitan district, however, with its new and separate sea outfall on the opposite side of the harbor, it was necessary to provide independent pumping plant. A study of the conditions, with special reference to the desirability of avoiding excessively deep excavation, chiefly in unfavorable ground and considerably below the level of low tide, resulted in the recommendation to pump the sewage at four different points. Upon this principle a succession of low lifts was adopted, with intervening main sewers at moderate depths, as opposed to carrying the sewage to a lower elevation at a single pumping station with a correspondingly heavier lift. Thus it comes, as will be gathered from a description of the works, that the bulk of the north metropolitan sewage is lifted twice and some of it three times before finally reaching the outlet at Deer Island light.

The Metropolitan Sewerage Commissioners.

The project outlined above received the approval of the Legislature, which, by chapter 439 of the Acts of 1889, constituted a Board of Metropolitan Sewerage Commissioners, consisting of three members, to "construct, maintain and operate" the necessary main sewers and other works, substantially as recommended by the State Board of Health in their report of 1889. The original commission consisted of Hosea Kingman (chairman), Tilly Haynes and R. T. Davis. Mr. Howard A. Carson was selected as chief engineer; he had been prominently identified with the studies of the State Board of Health. Subsequent changes in the commission and its officers are shown on page 39.

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* Medford and Everett were at that time under town government.

Additions to Original Metropolitan Sewerage District. — Successive Legislatures have added certain districts to the original area. Chapter 406 of the Acts of 1895 provided for the Neponset valley system, comprising parts of the West Roxbury and Dorchester districts of the city of Boston, together with the towns of Dedham, Hyde Park and Milton. The total area of this district amounts to about 44 square miles, of which about 17 square miles form the southerly portion of the original main drainage district of the city of Boston, previously referred to. The entire system connects by gravity with the Boston main drainage works at Granite Avenue, in Dorchester. By chapter 414 of the Acts of 1896, the southerly portion of the town of Wakefield, about one square mile in extent, was incorporated with the north metropolitan sewerage district. In like manner, by chapter 520 of the Acts of 1897, the town of Lexington was authorized to connect the sewerage systems of its central and eastern villages with the north metropolitan sewers, making a further addition of about 5 square miles to the metropolitan sewerage district.

High-level System. — A more important addition to the jurisdiction of the commission was effected in 1899, involving the construction, by that body, of the high-level sewer which had been foreshadowed, in 1875, as a feature of the Boston main drainage system. The conditions anticipated at the time when the Boston low-level system was designed had long been exceeded by the growth of the sewered area within the city, while the addition of the Charles River and Neponset valley districts made further large demands upon the capacity of the works. Heavy and increasing rentals were being paid by the Commonwealth to the city of Boston for the partial use of the city system, including the cost of pumping; and in 1898 the sewerage commissioners reported to the Legislature as to the growing need of relief, following this up, in 1899, by recommending the construction of a high-level sewer, with an independent gravity outfall into the harbor, off Nut Island. The Legislature gave effect to this recommendation by chapter 424 of the Acts of 1899. This added important districts in Roxbury, West Roxbury and Dorchester of the city of Boston, and the whole of the city of Quincy, representing an addition to the metropolitan sewerage district of about 21 square miles, so that to October 1, 1899, the metropolitan sewerage district includes an area of 185 square miles, as outlined in detail in the accompanying table and shown on the general map.

Table showing the Areas and Estimated Populations within the Metropolitan Sewerage District, October 1, 1899.

CITY OR TOWN.	Area (Square Miles).	Estimated Population, October 1, 1899.
Arlington,	5.196	7,783
Belmont,	4.657	8,768
Boston, portions of north metropolitan system,	3.450	90,381
Boston, portions of south metropolitan system,	20.915	98,960
Brookline,	6.807	19,391
Cambridge,	6.111	91,264
Chelsea,	2.240	33,779
Dedham,*	14.100	7,200
Everett,	3.340	24,516
Hyde Park,	4.572	13,646
Lexington,*	5.110	2,730
Malden,	5.074	36,101
Medford,	8.350	18,176
Melrose,	3.730	14,873
Milton,	12.589	6,624
Newton,	18.030	32,484
Quincy,	12.555	24,862
Somerville,	3.965	61,799
Stoneham,	5.495	6,776
Wakefield,*	.950	760
Waltham,	13.632	23,055
Watertown,	4.045	8,998
Winchester,	5.952	7,149
Winthrop,	1.613	5,558
Woburn,	12.705	15,555
Totals,	185.183	656,188

* Part of town.

Period of Construction.

Charles River System. — The construction of the metropolitan sewerage system was begun in May, 1890, soon after the organization of the Board. With work of this magnitude difficulties were frequently encountered, especially in the more thickly settled districts and where natural conditions of soil were unfavorable. However, such difficulties merely caused delays, and the work on the Charles River system progressed rapidly until its completion in the spring of 1892, when the system was at once put into operation.

North Metropolitan System. — Construction upon the north metropolitan system was carried on simultaneously with that of the Charles River, but, owing to the greater magnitude of the work, was slower in progress and much later in its completion. During the five years required to complete the system, no delays of a serious nature occurred. Such portions of the work as were too important to entrust to contract labor, or which involved possible changes of design to meet conditions as they arose, were constructed by day labor under the direct superintendence of the engineering force employed by the Board. This includes part of the outfall sewer in the main channel off Deer Island, crossings under streams, and the construction of large pump-wells connected with the four pumping plants. The three main pumping stations were all in operation in the summer of 1895, and the whole system, as originally authorized, has been in operation since the early part of 1896.

Neponset Valley System. — In the latter year work was begun on the Neponset valley system, the last of the three hitherto constructed by the Board. It was substantially completed in 1897.

Extensions. — The Wakefield and Lexington extensions were added to the north metropolitan system in 1897 and 1898.

High-level System. — Surveys and engineering studies in connection with this system are in progress. It is anticipated that several years will be required for the completion of the works, after October 1, 1899.

Expenditures.

The capital expenditures of the Board of Metropolitan Sewerage Commissioners to October 1, 1899, are as follows: —

SYSTEM.	EXPENDITURES.
Charles River,	$789,134 27
North metropolitan,	5,262,397 68
Neponset River,	840,444 73
High-level,	44,608 46
Total,	$6,936,585 14

This represents the total outlay for about 70 miles of main sewers, with four pumping stations, harbor outfall, siphons under streams, and other appurtenances. The sum included for the high-level system has been expended out of an appropriation of $4,600,000 on the preliminary studies, together with the detailed surveys and engineering investigations connected with the work of construction. The capital expenditure on the whole undertaking has been met by the proceeds of bonds, issued by the Commonwealth, usually bearing interest at the rate of 3 per cent. per annum. The bonds for the Charles River and north metropolitan systems mature on January 1, 1930, and those for the Neponset River system on March 1, 1935.

Apportionment of Cost of Construction, Maintenance and Operation.

All of the sewerage acts provide in the same terms that the expenditure incurred by the Commonwealth in the construction of the several systems shall be repaid by the cities and towns included therein, in annual payments sufficient to meet the accruing interest on the respective sewerage loans, and sufficient also to create sinking funds which, with their accumulations, will extinguish the loans at their maturity. The cities and towns are required in like manner to reimburse to the Commonwealth the annual cost of maintenance and operation.

The apportionment of the sinking funds is designed to cover the whole expenditure in forty years; but in order to bring the payments more nearly into proportion to the

PLATE I

increased use of the system by a growing population, it is provided by the acts that, instead of recovering one-fortieth of the entire sum in each year, the repayment shall be apportioned as follows: 5 fortieths in the first ten years, 6⅔ fortieths in the second ten years, 13⅓ fortieths in the third ten years, and 15 fortieths in the fourth ten years.

The several acts further provide for the appointment by the supreme judicial court of three commissioners, not residents of the sewerage district, whose duty it shall be to determine the proportions in which the several cities and towns in each system shall annually, for the term of five years next following the year of the first issue of sewerage scrip or certificate of debt, pay money into the treasury of the Commonwealth, first, to meet the interest and sinking fund requirements for each of said years, as estimated by the Treasurer; and, second, to meet the cost of maintenance and operation for each of said years, as estimated by the Board of Metropolitan Sewerage Commissioners and certified to the Treasurer.

Two apportionment commissions have thus far been appointed; they have in each case based the repayment of the loans (representing the capital cost of the undertaking) upon the valuation of the cities and towns, while the payments on account of maintenance and operation have been apportioned according to the respective populations. The gross amounts for interest and sinking fund charges, and for the cost of maintenance and operation, are assessed upon the individual cities and towns in the respective ratios certified by the apportionment commissioners, and collected as part of the State tax.

The following table shows the estimated populations, valuations and amounts assessed on the component areas of the sewerage district for interest and sinking fund charges and for maintenance and operation in the year 1899: —

Table showing Estimated Population, Valuation and Assessments of the Metropolitan Sewerage District for the Year 1899.

CITY OR TOWN.	Estimated Population, October 1, 1899.	Gross Valuation of Real and Personal Estate, Chap. 232, Acts 1898.	ASSESSMENTS.		
			Interest and Sinking Fund.	Maintenance and Operation.	Total.
Arlington, . . .	7,788	$8,976,266	$5,592 31	$1,691 55	$7,283 86
Belmont, ...	3,768	4,815,982	2,653 81	737 10	3,390 91
Boston,* north metropolitan district.	90,381	62,269,900	38,757 45	21,564 90	60,322 35
south metropolitan district.	98,960	223,190,800	13,929 90	18,589 68	32,519 58
Brookline, . . .	19,391	74,251,728	8,132 87	7,693 86	15,826 73
Cambridge, . . .	91,264	92,791,563	53,528 93	21,234 15	74,763 08
Chelsea, ...	33,779	23,673,450	15,063 77	8,136 45	23,200 22
Dedham,* . . .	7,200	8,250,000	4,232 65	4,287 20	8,519 85
Everett, ...	24,516	15,065,406	8,195 35	4,828 95	13,024 30
Hyde Park, . . .	13,646	9,729,118	5,675 87	7,669 45	13,345 32
Lexington,* . . .	2,730	3,088,688	2,494 88	-	2,494 88
Malden, ...	36,101	29,849,388	16,744 02	7,730 10	24,474 12
Medford, ...	18,176	19,391,980	10,803 37	3,761 10	14,564 47
Melrose, ...	14,873	12,693,425	6,583 73	3,061 80	9,645 53
Milton, ...	6,624	22,192,943	14,109 86	3,563 67	17,673 53
Newton, ...	32,484	59,103,233	6,202 43	13,265 28	19,467 71
Somerville, . . .	61,799	51,475,670	29,278 44	13,579 65	42,858 09
Stoneham, . . .	6,776	4,945,050	2,608 03	1,634 85	4,242 88
Wakefield,* . . .	760	822,763	569 38	170 10	739 48
Waltham, . . .	23,055	19,627,274	2,448 80	10,128 99	12,577 79
Watertown, . . .	8,998	10,282,882	1,090 34	3,775 87	4,866 21
Winchester, . . .	7,149	7,968,162	4,499 32	1,597 05	6,096 37
Winthrop, . . .	5,558	6,142,687	3,052 95	1,086 75	4,139 70
Woburn, ...	15,555	10,582,137	6,441 37	3,685 50	10,126 87
Totals, . . .	631,326	$781,180,495	$262,689 83	$163,474 00	$426,163 83

* Part of town.

NOTE.—At the date of this assessment Quincy was not included in the metropolitan district.

It appears from this table that the total assessment for 1899 represents one-twentieth of one per cent. of the gross valuation of the whole metropolitan district, or a sum of 67 cents per capita on the estimated total population for that year.

DESCRIPTION OF THE COMPLETED WORKS.

The Charles River System. — The Charles River system provides an outlet for the local sewers of Waltham, Watertown, most of Newton, Brighton (part of Boston), most of Brookline and part of the Back Bay district of Boston.

The system was designed to meet the prospective conditions in 1930, including an estimated population of 183,000, for which a sewer capacity at the rate of 30 cubic feet per head per twenty-four hours was provided. This represents a maximum rate of flow equal to 64 cubic feet per second. The system consists of 8.1 miles of intercepting sewer in a single line, shown on the general map. Commencing in Waltham as a 3′ 6″ × 4′ sewer, it becomes by successive enlargements 6′ 6″ in diameter at its junction with the Boston main drainage system at the intersection of Gainsborough Street and Huntington Avenue, where the invert level is about 5 feet below mean low water. The lengths, sizes and rates of inclination of this system are given in the following table: —

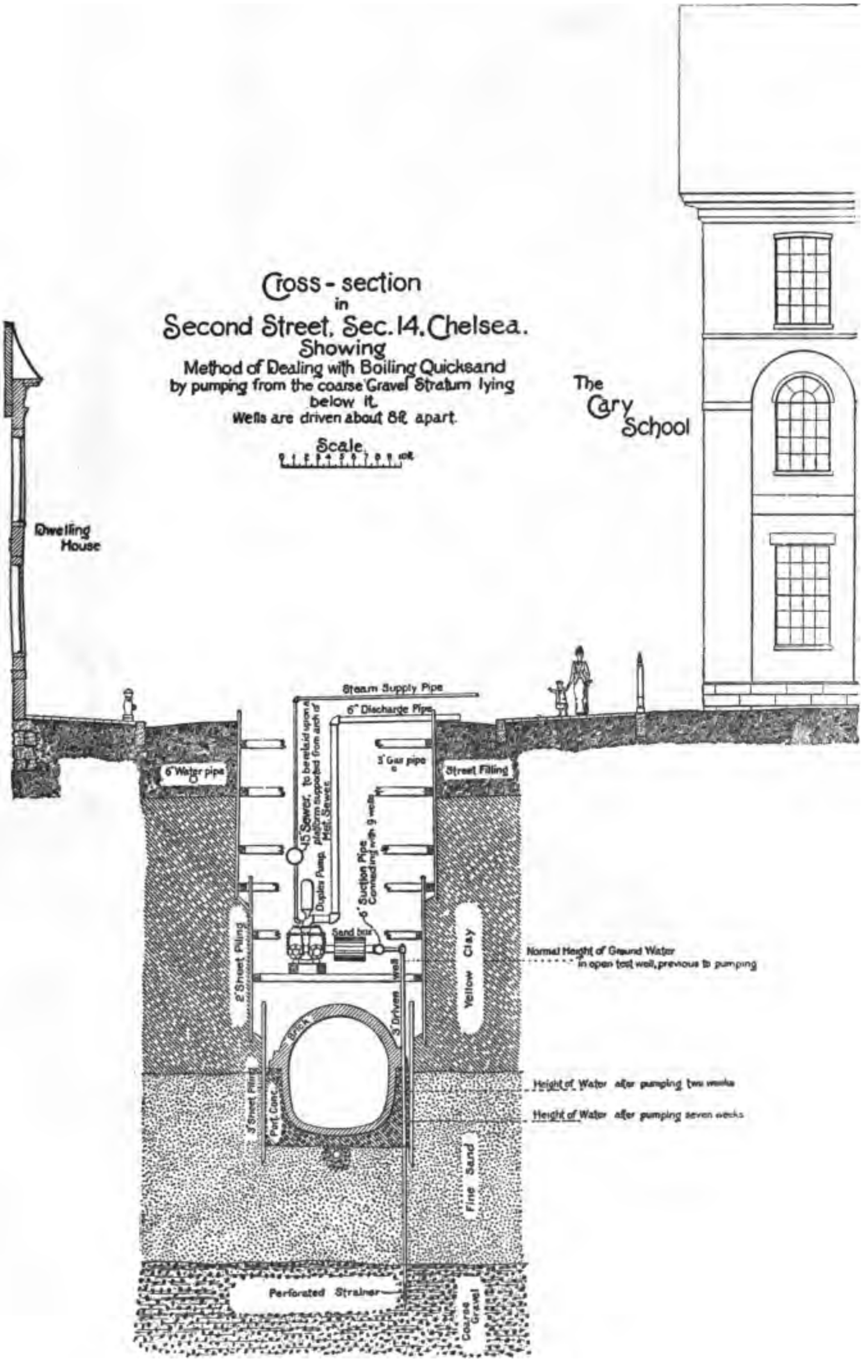
CHARLES RIVER SYSTEM.

Table showing Locations, Lengths, Sizes and Inclinations of Metropolitan Sewers within the Charles River Valley Area.

CITY OR TOWN.	Size of Sewers.	Length in Miles.	Gradients.
Part of Boston proper,	6′ 6″ to 5′ 6″,	1.500	1:2500
Boston (Brighton),	5′ 6″ to 4′ 2″ × 4′ 9″,	3.688	1:2500
Brookline,	5′ 6″,	0.127	1:2500
Newton,	4′ 2″ × 4′ 9″ to 3′ 6″ × 4′,	2.057	From 1:2500 to 1:1500
Watertown,	4′ 2″ × 4′ 9″ to 3′ 11″ × 4′ 5″,	0.725	1:2500
Waltham,	3′ 6″ × 4′,	0.001	1:1500
		8.098	

North Metropolitan System. — The north metropolitan system consists of a main line and several branches, with a total length of 50.8 miles. Of the latter, the Cambridge branch is the most important. Representative cross-sections of sewers in this system are shown on Plate 1. An anticipated volume of sewage on the basis of 30 cubic feet per head per twenty-four hours is provided for, except in Cambridge and Somerville, where the sewerage systems are mainly of the " combined" type and in many cases below tide level. For these two cities a basis of 35 cubic feet per head was adopted. New sewerage systems are designed to exclude storm water. For an estimated population of 571,000 in 1930 these allowances yield in the aggregate a maximum flow at the rate of 210 cubic feet per second. Commencing in Stoneham, about 18 miles from Deer Island light, the main line follows the valley of the Abbajona River to a point below Winchester, and continues thence, in the bed of the old Middlesex canal, to a point near the dam between the upper and lower Mystic lakes. Here it is joined by the old Mystic valley sewer, built in 1877 and 1878 by the city of Boston to prevent the pollution of the upper lake, at that time one of the sources of the city water supply. Part of the old sewer was purchased by the commissioners and adopted as a local branch, to take the sewage of the greater part of Woburn (through the Cummingsville branch) and a section of Winchester. The metropolitan sewer continues down the valley, alongside the southern division of the Boston & Maine Railroad, to West Medford. It there receives the Alewife Brook branch, contributing sewage which has been lifted about 13½ feet, at the Alewife Brook pumping station, from Belmont, Arlington and (ultimately) Lexington, as well as from low-lying areas of Cambridge, Somerville and Medford. Continuing through Medford, it is joined at Wellington village, in the eastern section of that city, by the Edgeworth branch, carrying the sewage of the westerly section of Malden. On leaving Wellington, the metropolitan sewer passes under the Malden River by an inverted siphon, and is joined near West Everett station by the branch from East Stoneham, Wakefield, Melrose and the larger part of Malden. About three-quarters of a mile further on, in the marsh near Everett station, it receives the high-level discharge sewer, into which the sewage from Cambridge, Somerville, Charlestown and parts of Medford have been pumped, together with the sewage

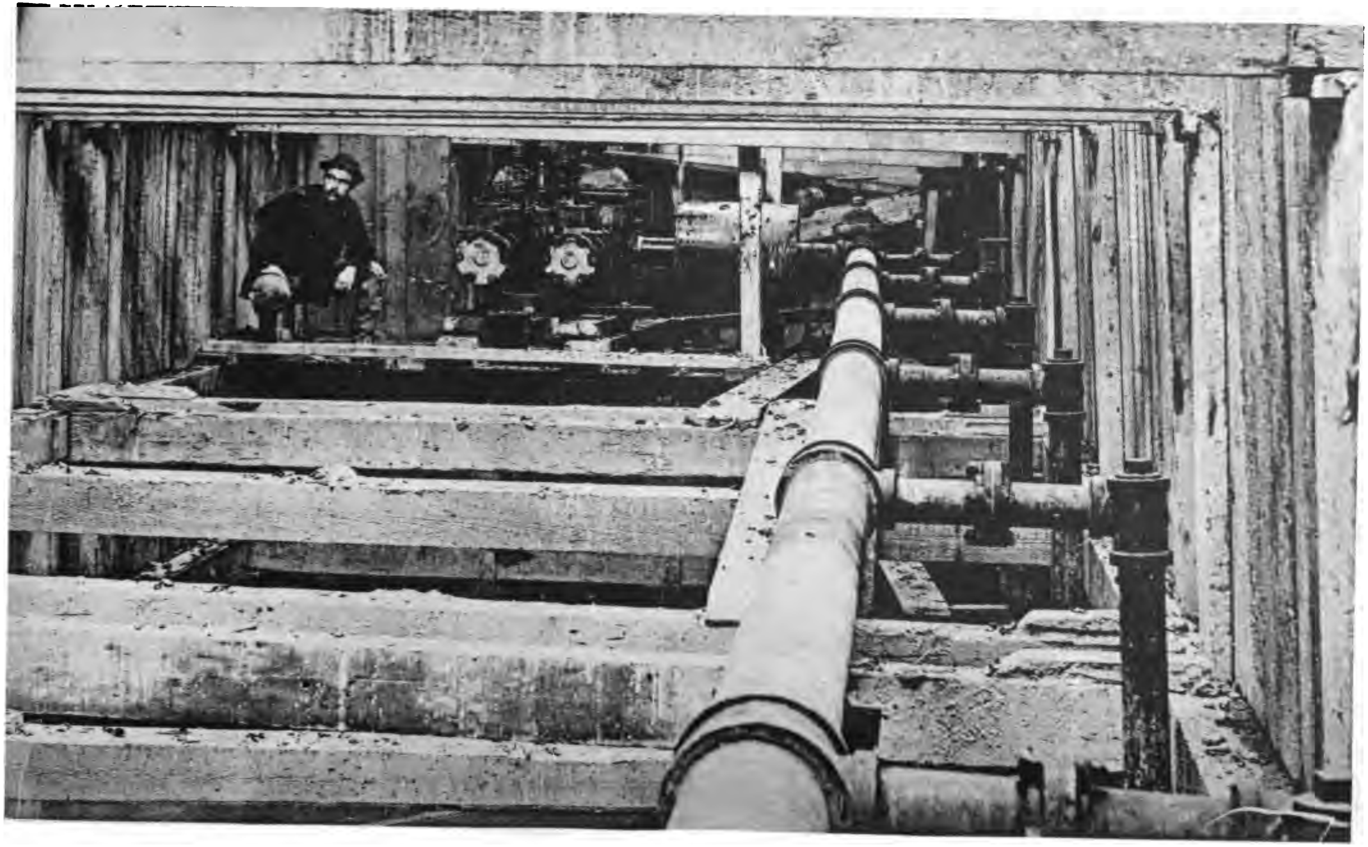
Plate 2.



Cross-section
in
Second Street, Sec. 14, Chelsea.
Showing
Method of Dealing with Boiling Quicksand
by pumping from the coarse Gravel Stratum lying
below it.
Wells are driven about 8ft. apart.

Scale
0 1 2 3 4 5 6 7 8 9 10ft.
Dwelling House
The Cary School
Steam Supply Pipe
6" Discharge Pipe
6" Water pipe
3" Gas pipe
Street Filling
15" Sewer, to be relaid upon a platform supported from arch of Met. Sewer.
Duplex Pump
6" Suction Pipe Connecting with 9 wells
Sand box
2" Sheet Filling
Yellow Clay
3" Driven Well
Brick
Port. Conc.
3" Sheet Filling
Normal Height of Ground Water in open test well, previous to pumping
Height of Water after pumping two weeks
Height of Water after pumping seven weeks
Fine Sand
Perforated Strainer
Coarse Gravel

Plate 3.



Pipe-wells for tapping water-bearing stratum below quicksand—Second Street, Chelsea.

from a small part of Everett. It then passes through Chelsea and along a part of the water front, where it is joined by a branch intercepting the sewage from the easterly section of Chelsea. The main sewer then passes by a siphon under Chelsea Creek, to the East Boston pumping station, where the whole volume of sewage, with the added contribution of the East Boston intercepting system (built by the commissioners), is lifted about 15 feet. Continuing through East Boston and Breed's Island, it passes under Belle Isle Inlet by three parallel siphons, traverses the town of Winthrop, and is then carried under the navigable strait known as Shirley Gut by yet another siphon to Deer Island, where a pumping plant lifts the sewage to such average elevations, varying from about 6 to 15 feet, as are required by the fluctuations of the tide. The discharge sewer from this station follows the western shore to the southern end of the island, and is then carried about 1,860 feet into the harbor by a masonry outfall sewer. The outfall was designed for the continuous discharge of sewage, without any provision for storage during the period of incoming tide or longer. Deer Island affords facilities for the construction of storage reservoirs, if such additions should ever become desirable; but, having regard to the favorable geographical position of the selected outlet, and to the velocity of the current into which the sewage is discharged, storage was not considered necessary. The continuous operation of the works for about five years has amply confirmed the correctness of this decision.

The Cambridge Branch.—The upper end of the Cambridge branch is in the westerly section of that city, about 15 miles distant from the Deer Island outlet, and about 6½ miles from its junction with the main line near Everett station. It follows generally the line of streets in the vicinity of the Charles River, at a sufficient depth to pass below and intercept the sewers formerly discharging into the river. In Sullivan Square, Charlestown, it receives the Charlestown branches, and about a quarter of a mile further on is joined by a branch draining parts of Somerville and Medford. The sewer then passes by a siphon under the Mystic River to a pumping station on the opposite bank, where the sewage is lifted about 8 feet into the high-level discharge sewer, already referred to.

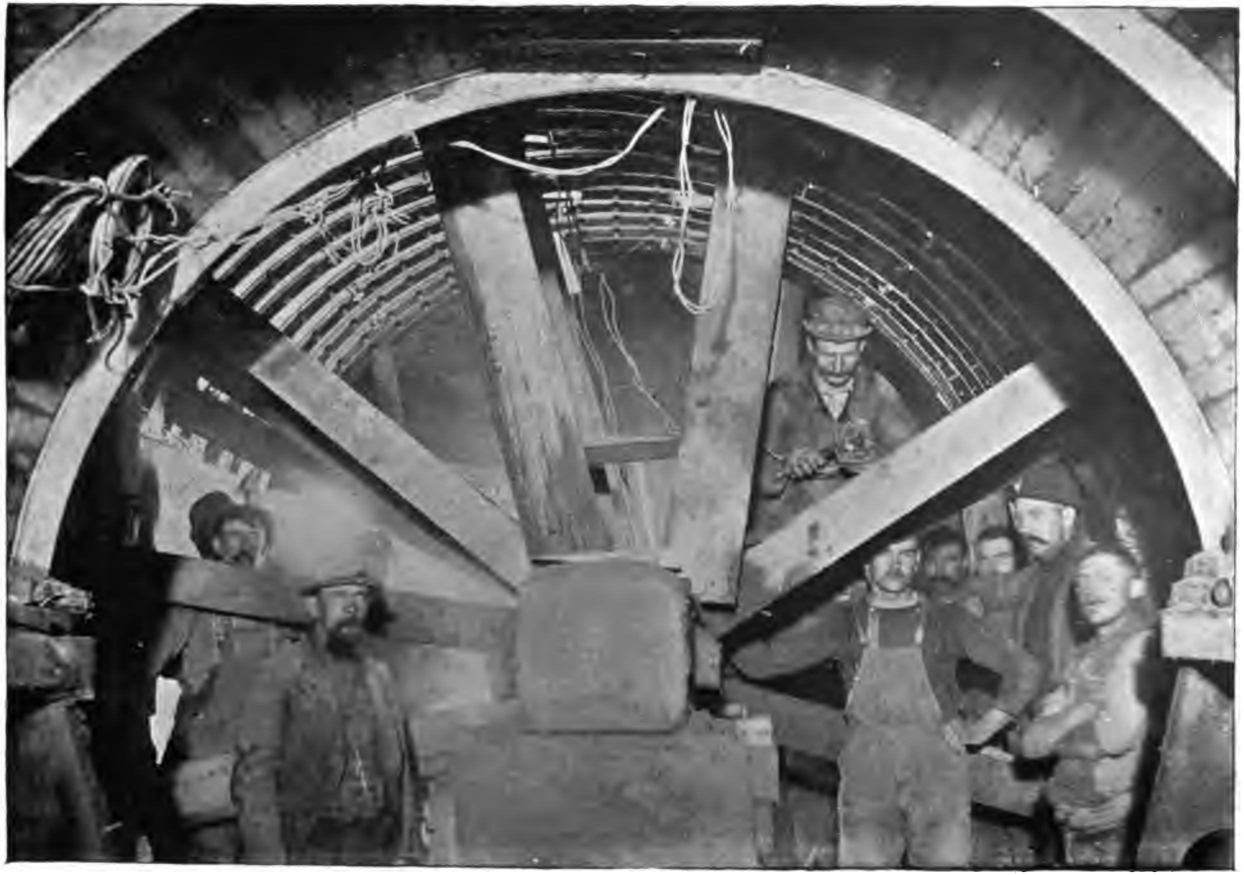
Special Features. — Many features of interest, both in design and construction, were developed by the necessities of the north metropolitan system. Some of these, illustrated by plates 1 to 14, are referred to below.

Quicksands. — The excavation of the sewer trenches was attended, in places, with much difficulty, owing to the unfavorable character of the sub-soil, especially by the occurrence of quicksands. Along the water fronts and elsewhere the progress of the work was seriously impeded by this obstacle, it being found practically impossible, by ordinary methods, to free the excavation from the volume of boiling sand forced up by the pressure of water lying several feet below the construction plane. Tubular wells were sunk at frequent intervals into the water-bearing stratum, and connected, in the trench, by horizontal piping, leading to a steam pump, as shown on plates 2 and 3. In this way the head of water above the bottom of the trench was sufficiently lowered to prevent the forcing up of sand, and operations were carried on as in ordinary excavation. This method was successfully used on several sections of the work.

Use of Compressed Air. — Tunnels under the Mystic River and Chelsea Creek and in quicksands in deep excavation were worked by the aid of air-locks. Pressures up to about 18 pounds per square inch, in excess of the atmosphere, were maintained in the working lengths. Plate 4 shows the method of supporting the tunnel roof in quicksand by a needle-bar and curved steel plates. Plates 5 and 6 show the construction of the tunnel under the Mystic River with the aid of compressed air.

Shirley Gut Siphon. — At the point selected for the crossing of the north metropolitan main sewer, Shirley Gut is 315 feet wide at mean high water, with a depth of 25 feet of water in the middle. The tidal current practically never ceases; it is so swift that the building of a temporary timber bulkhead across the strait was necessary before commencing work on the inverted siphon. The construction adopted for the pipe was essentially novel. Six

Plate 4.



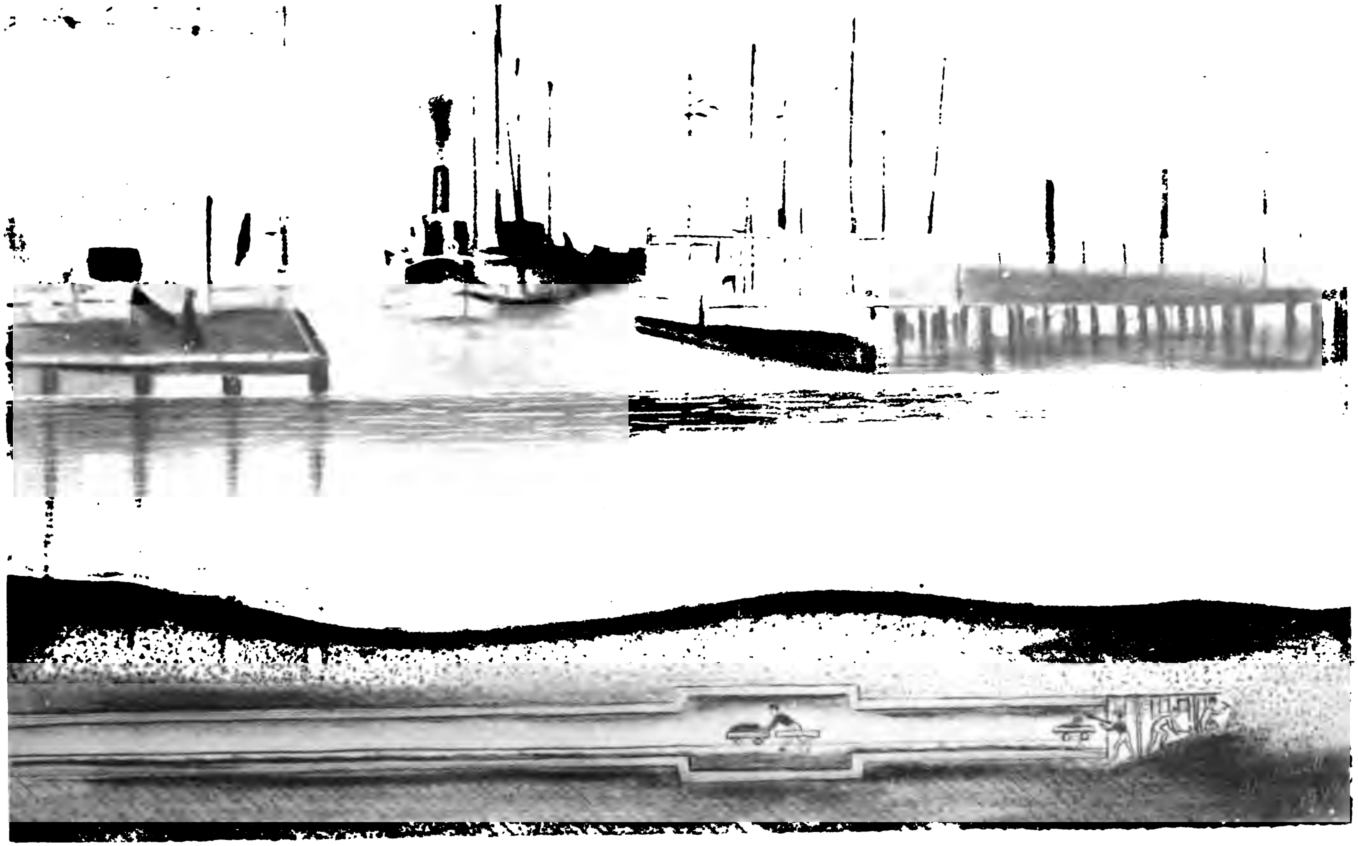
Heading of Air Tunnel in Quicksand, Second Street, Chelsea.

sections of riveted tank-steel shell, ⅜ of an inch thick, 8 feet 5 inches in diameter, with a total length of 264 feet, were constructed on the beach and lined with three rings of Portland cement brickwork, leaving the internal diameter of the tube 6 feet 2 inches. Two of these sections were short man-hole specials; the others varied from 48 feet to 68 feet in length, and weighed, when lined and bulkheaded in readiness for floating, from 80 to 112 tons each. They were so curved as to form a depression of 22 feet in the axial line of the completed work. The separate sections were closed by strong timber bulkheads, furnished with valves, and floated at high water alongside of scows provided with hoisting gear, as shown on Plate 7. They were partially filled with water through the valves, and lowered singly into a trench previously dredged for their reception, where they rested upon sills which had been accurately set by divers. The sections were afterwards bolted together by divers, the bulkheads removed and the water pumped out through the man-hole sections, thus enabling the short lengths of brickwork to be built inside. The interior was finally lined very smoothly with Portland cement mortar rammed into place, elm-hoop furrings, soaked in hot paraffine and fastened with heavy copper rivets, being used in this work. Plate 8 shows a section on the beach, ready for launching.

Deer Island Outlet.—In the laying of a 6¼ foot outfall sewer to a point abreast of Deer Island light, 1,860 feet beyond the shore line at high water, two methods were adopted. The shore end of the work, for a length of 674 feet, was constructed by excavation within a coffer-dam. Beyond this point recourse was had to a modification of the system adopted at Shirley Gut, built-up timber lagging being used instead of steel shells. The sewer was formed of separate sections, each about 52 feet long. Instead of building these on the beach, they were constructed on specially designed timber cradles built at each side of a pier, erected by the commissioners in connection with the Deer Island pumping station, as shown on Plate 9. The cradles were suspended from a system of gearing operated by a portable engine, capable of raising or lowering the cradle and sewer sections uniformly throughout. The sewer sections were built of 4-inch spruce lagging, lined with 6 inches of concrete and 8 inches of brickwork. The work was carried on as in an ordinary sewer trench, the invert being first constructed and the arch then turned on centres. The completed lagging was then surrounded with strong oak hoops at intervals of two feet, and the two ends bulkheaded. The weight of each section, ready for floating, was about 95 tons. After the cradle had been lowered into the water by the gearing, the sewer section was floated out and towed, as shown on Plate 10, to its position over a dredged trench, and lowered by travelling shears running on a temporary pile-work, as illustrated by Plate 11. It was then bolted by divers to the work already in position, and a back-filling of gravel over the whole length completed the external work. The gaps in the brickwork lining were subsequently filled up from the inside The whole of the outfall sewer was constructed by day labor.

Pumping Stations. — The pumping plants for the two main line stations (Deer Island and East Boston) and for the Cambridge branch (Charlestown) consisted at first of two pumping engines, with the necessary boilers, piping, etc. Additional engines and boilers of the same general type as those originally installed are being erected at each of these stations. Each engine at the Deer Island and East Boston stations is capable of easily raising 70 cubic feet of sewage per second 19 feet vertically above the level of the sewage in the pump well, and of raising to greater heights, up to 25 feet, quantities of sewage inversely proportional to such lifts. It is also capable of pumping at as low a rate as 15 cubic feet per second, and at all rates between that and the maximum rate of 70 cubic feet. The pumps are of the centrifugal type, with vertical shafts. The pump wheels, 8 feet 3 inches in diameter, run at speeds varying from 60 to 100 revolutions per minute according to the volume of sewage and the height to which it is lifted. Each pump wheel is driven by a triple-expansion condensing engine of the Reynolds-Corliss type, the three cylinders being set at angles of 60°, in order to give uniform turning movement on the crank. The cylinders

Plate 5.



Longitudinal Section, Mystic River Tunnel.

are 13½, 24 and 34 inches in diameter, with 30 inches stroke. In the Charlestown pumping station the capacity of each engine is 35 cubic feet per second, raised 11 feet high, with similar provisions as to varying height. The pump wheels are 7 feet 6 inches in diameter. The cylinders are 9¼, 16½ and 23 inches in diameter, with 30 inches stroke. Additional engines and boilers are likewise being installed at this station. These pumping plants are of special design, and were built and erected by the Edward P. Allis Company of Milwaukee, Wis. In the contract duty and capacity tests to which the three plants were subjected, taking the mean of two engines in each case, the duty developed was 94,814,724, 91,781,682 and 89,723,074 foot-pounds at Deer Island, East Boston and Charlestown respectively. The efficiencies of the centrifugal pumps (W. H. P. ÷ I. H. P.) were respectively 62 per cent., 57 per cent. and 52 per cent.

The general arrangement of the pumping stations is shown in plan by Plate 12. Plate 13 gives an interior view and Plate 14 an exterior view of the Deer Island station. Particulars of the sewers comprising the north metropolitan system are given in the following table: —

NORTH METROPOLITAN SYSTEM.

Table showing Locations, Lengths, Sizes and Inclinations of Metropolitan Sewers within the North Metropolitan Area.

CITY OR TOWN.	Size of Sewers.	Length in Miles.	Gradients.
Boston: —			
Deer Island,	6′ 3″ to 9′,	1.367	From 1:3200 to 1:73.6
East Boston,	9′ to 1′,	5.467	From 1:3000 to 1:50
Charlestown,	6′ 7″ × 7′ 5″ to 1′,	3.292	From 1:3250 to 1:66.7
Winthrop,	9′,	2.864	1:3200
Chelsea,	8′ 4″ × 9′ 2″ to 2′ 1″ × 2′ 10″,	2.212	From 1:3000 to 1:800
Everett,	8′ 2″ × 8′ 10″ to 4′ 8″ × 5′ 1″,	2.925	From 1:3000 to 1:1400
Malden,	3′ 9″ × 4′ 1″ to 1′ 3″,	3.140*	From 1:2500 to 1:100
Melrose,	1′ 10″ × 2′ 9″ to 10″,	3.843†	From 1:1062 to 1:13.9

* This includes .99 of a mile of sewer purchased from the city of Malden.

† This includes .736 of a mile of sewer purchased from the town of Melrose.

Table showing Locations, Lengths, Sizes, etc.—Concluded.

CITY OR TOWN.	Size of Sewers.	Length in Miles.	Gradients.
Cambridge, . .	5' 2" × 5' 9" to 1' 3", . . .	5.963	From 1:2200 to 1:1500
Somerville, . .	6' 5" × 7' 2" to 1' 10" × 2' 3", .	3.471	From 1:3000 to 1:1000
Medford, . . .	4' 8" × 5' 1" to 10", . . .	5.359	From 1:2000 to 1:1040
Winchester, . .	2' 11" × 3' 3" to 1' 8", . . .	6.403	From 1:2250 to 1:250
Stoneham, . .	1' 3" to 10", ...	.010	From 1:500 to 1:125
Woburn, . . .	1' 10" × 2' 4" to 1' 3", . . .	.933	From 1:1000 to 1:166.7
Arlington, . .	1' 6" to 10", ...	3.520*	From 1:588 to 1:83.3
Belmont,† . .	– –	–	– –
Wakefield†, . .	– –	–	– –
		50.769‡	

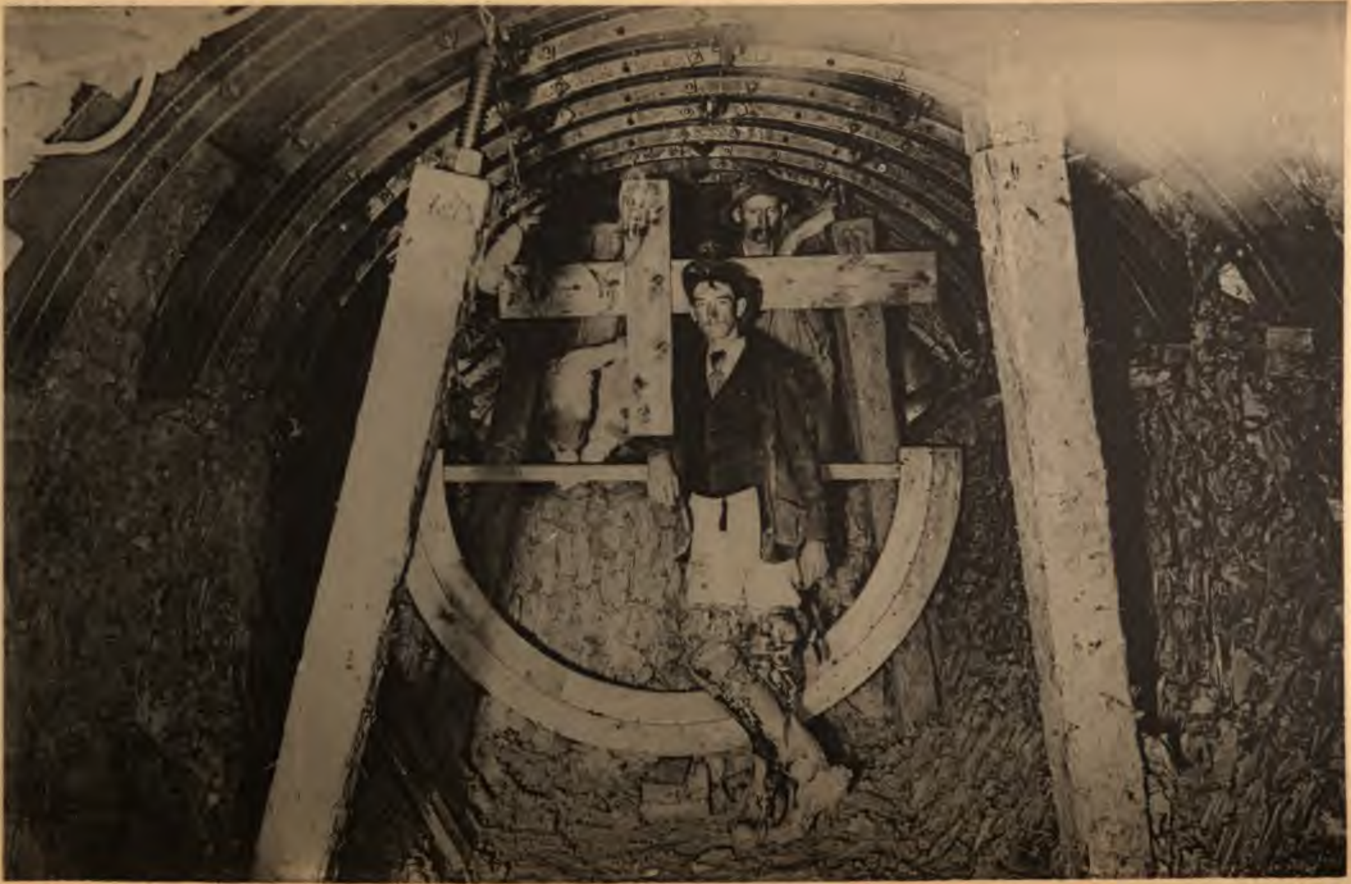
* This includes 2.631 miles of sewer purchased from the town of Arlington.

† The metropolitan sewer extends but a few feet into the towns of Belmont and Wakefield.

‡ This includes 2.7 miles of Mystic valley sewer in Medford, Winchester and Woburn running parallel with the metropolitan sewer.

Neponset Valley System.—The Neponset valley system consists of a single line of sewer, 11.30 miles in length, of which 1.24 miles, being part of the Dorchester interceptor of the Boston main drainage system, was purchased by the Commonwealth from the city of Boston. The head of the system is in the West Roxbury section of Boston, where it is 12 inches in diameter. It gradually enlarges, until in the lower part of Hyde Park, at the future intersection of the high-level sewer, its size is 4 feet 6 inches by 4 feet 7 inches. From this point its size is mainly 3 feet by 4 feet, the permanent function of the reduced cross-section being to deal only with the sewage of the area lying east of the high-level sewer, as shown on the general map. The sewer capacity for the permanent conditions was based upon a maximum flow equal to 30 cubic feet per head per twenty-four hours, on an estimated 1930 population of 213,000, or at the rate of 74 cubic feet per second. Details are given in the following table:—

Plate 6.



Mystic River Tunnel: Construction under air pressure.

NEPONSET VALLEY SYSTEM.

Table showing Locations, Lengths, Sizes and Inclinations of Metropolitan Sewers within the Neponset River Valley Area.

CITY OR TOWN.	Size of Sewer.	Length in Miles.	Gradients.
Milton, ...	1' 8" to 8", ...	0.05	1:770
Boston (Dorchester), .	3' × 4' to 2' 6" × 2' 7", . .	2.87*	From 1:2000 to 1:250
Hyde Park, . . .	4' 6" × 4' 7" to 4' × 4' 1", .	3.09	1:1000
Dedham, ...	4' × 4' 1" to 3' 9" × 3' 10", .	2.35	From 1:2000 to 1:1000
Boston (West Roxbury), .	3' 9" × 3' 10" to 1', . . .	2.94	From 1:2000 to 1:119
		11.30	

* This includes 1.24 miles of sewer purchased from the city of Boston.

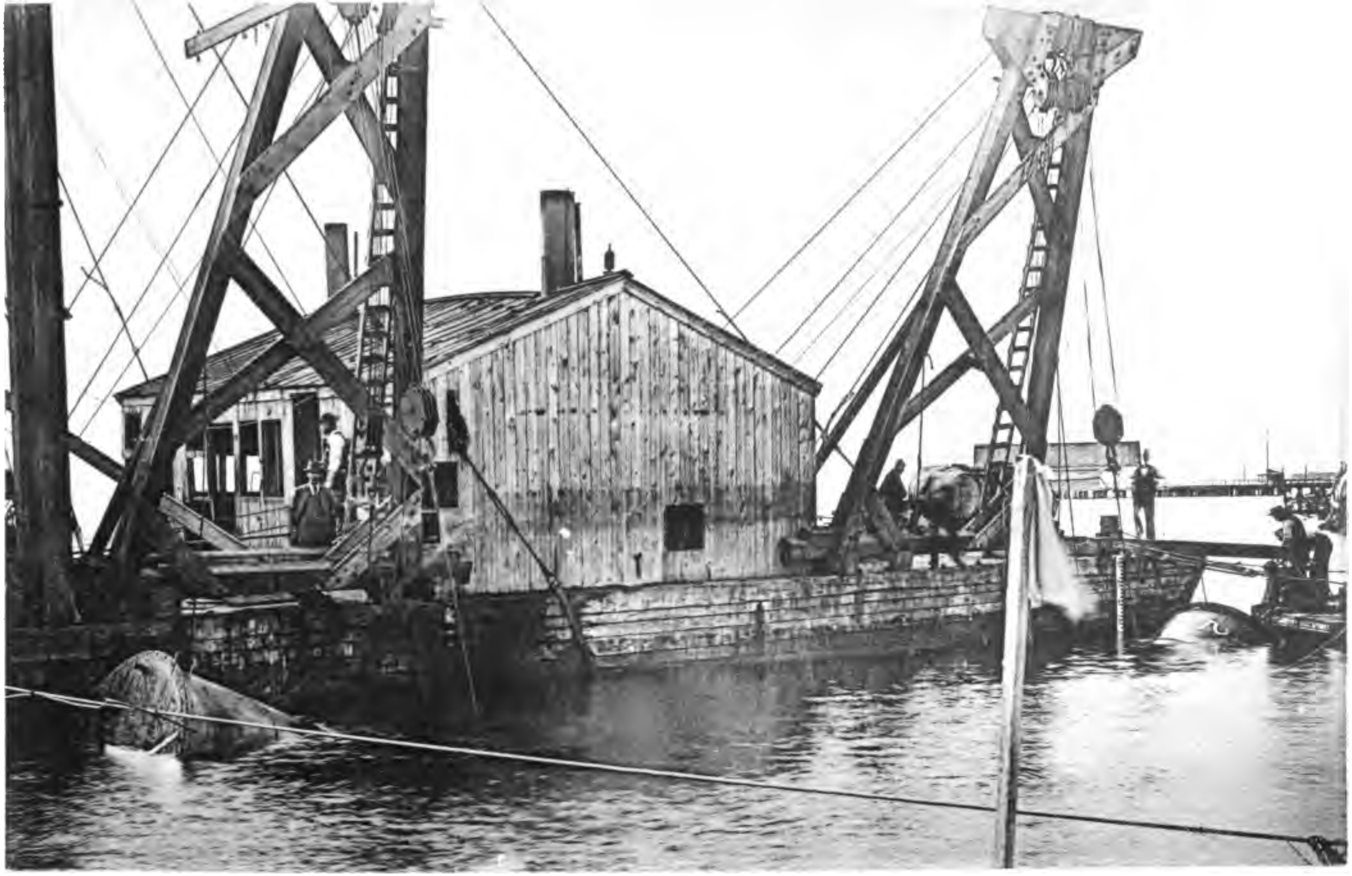
THE SOUTH METROPOLITAN SEWERAGE DISTRICT.

Leading Features of the High-level System. — The legislative act authorizing the construction of the high-level system deals with the Charles and Neponset River areas, already under the jurisdiction of the Metropolitan Sewerage Commission, together with new high-level territory. These are grouped into a new district, embracing all the metropolitan areas south of the Charles River, together with Watertown and Waltham, north of the river, to be hereafter known as the south metropolitan sewerage district. This area and the leading data of the proposed works are shown on the general map. The object of the undertaking is to provide for as large a portion of the district as possible by gravity, leaving the remainder to be dealt with by pumping. After the construction of the high-level sewer, the sewage of the Charles River valley, now discharged into the Boston main drainage system at Gainsborough Street, will be diverted to a pumping station, to be erected near the intersection of Huntington and Longwood avenues, and there raised about 40 feet into the high-level system. The high-level sewer will receive at various points, by gravity, the sewage from important areas of Boston, and will intercept in the same way the drainage from 42 of the 44 square miles originally embraced in the Neponset River area. The city of Quincy will also be tributary to the high-level system, partly by pumping, partly by gravity.

Population and Sewage Volume. — The sewer capacities for the high-level system are based upon the anticipated conditions in 1940, which include a population of 986,000. A rate equal to 300 gallons per head per twenty-four hours has been adopted, to cover all contingencies likely to arise. Applied to the estimated population, this represents a maximum flow of 458 cubic feet per second in 1940.

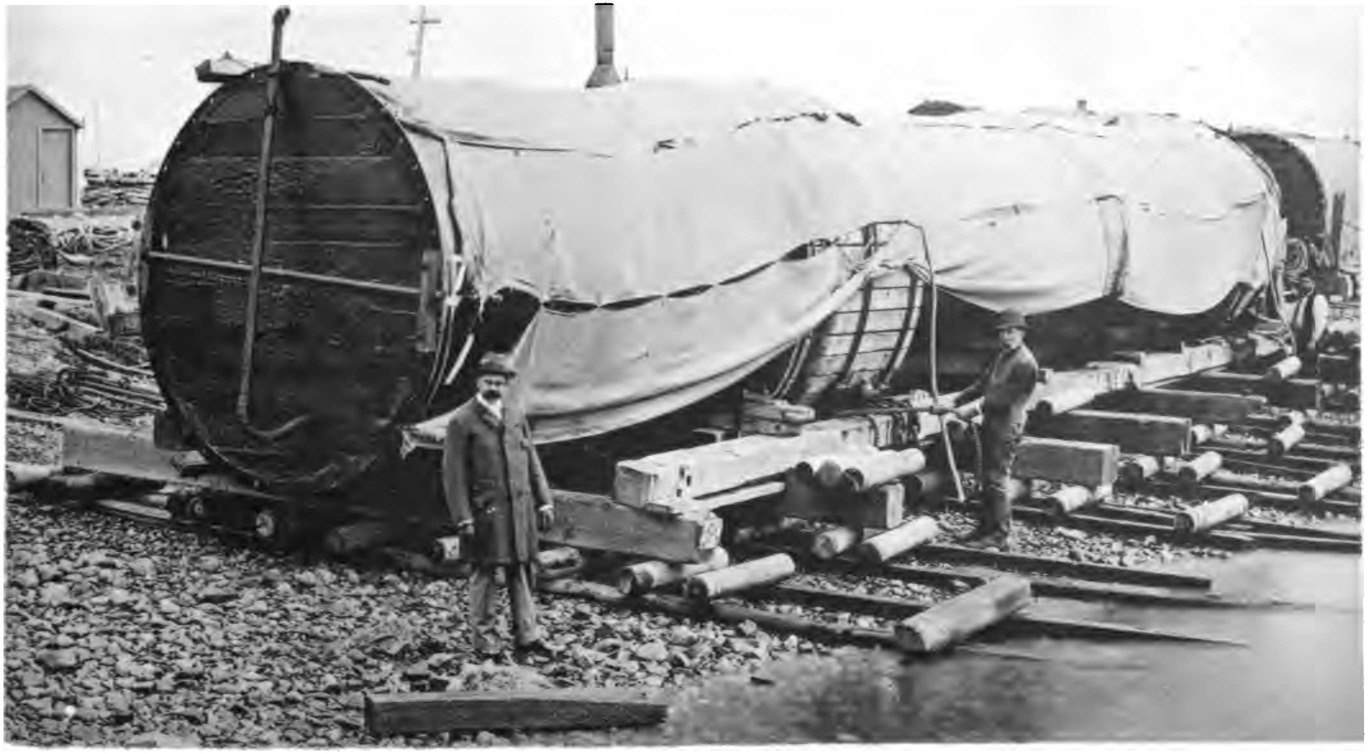
Structural Features. — The sewer for diverting the sewage of the Charles River system to the new pumping station will be 6 feet 6 inches in diameter and about 1,400 feet long. The two cast-iron force mains, of 48-inch pipe, will deliver into a 6 feet 6 inch sewer, about 2,500 feet long, terminating near Catalpa Street, in West Roxbury, with an invert elevation of about 31½ feet above mean low water. At this point provision will be made for receiving a high-level sewer for the more elevated areas of Newton, Brighton and Brookline, which may be constructed in the future, but it is not anticipated that this section will be needed for several years. The necessary increase in size will bring the dimensions of the proposed main line sewer below the junction to 8 feet 3 inches by 8 feet 9 inches. The sewer will pass on the north-east of Jamaica Pond, following the west side of the Stony Brook valley. It will be carried through the divide to the easterly end of Hyde Park, where the Neponset valley metropolitan sewer will be intercepted. Its course to Quincy will be through the valleys of the Pine Tree and Unkety brooks, in Milton; it will pass through Quincy as an 11 feet 3 inches by 12 feet sewer to Nut Island, where its invert elevation will be about 10 feet above mean low water. At Nut Island a screen-house and sand-catcher will be built, from which heavy cast-iron pipes, 5 feet in diameter, will be carried into the harbor for about three-quarters of a mile, discharging at the bottom of the channel into a depth of 26 feet of water at low tide. Provision will be made for additional lines of outfall pipe, to be laid as required. The total length of the proposed main line of sewer is about 16 miles. Its inclination from Catalpa Street junction to Nut Island will be 1 : 3,500. The estimated cost of the system, including 16 miles of large sewers, the pumping station for the Charles River valley sewer,

Plate 7.



Middle Section of Shirley Gut Siphon, after turning and before lowering into dredged channel.

Plate 8.



Shirley Gut Siphon: Section on beach, ready for launching.

crossings under streams, outfall works, and the estimated cost of acquiring the Quincy pumping plant, is about $4,600,000.

Summary of Expenditures.

By the city of Boston, for its main drainage works, to October 1, 1899, ...	$6,500,000
By the Metropolitan Sewerage Commissioners, for metropolitan systems, to October 1, 1899, ...	6,936,585
Prospective expenditures by the Metropolitan Sewerage Commissioners, on account of the construction of the high-level system, ...	4,600,000
	$18,036,585

A total of about $18,000,000 as the actual and prospective expenditures for the main drainage works of the city of Boston and the metropolitan systems.

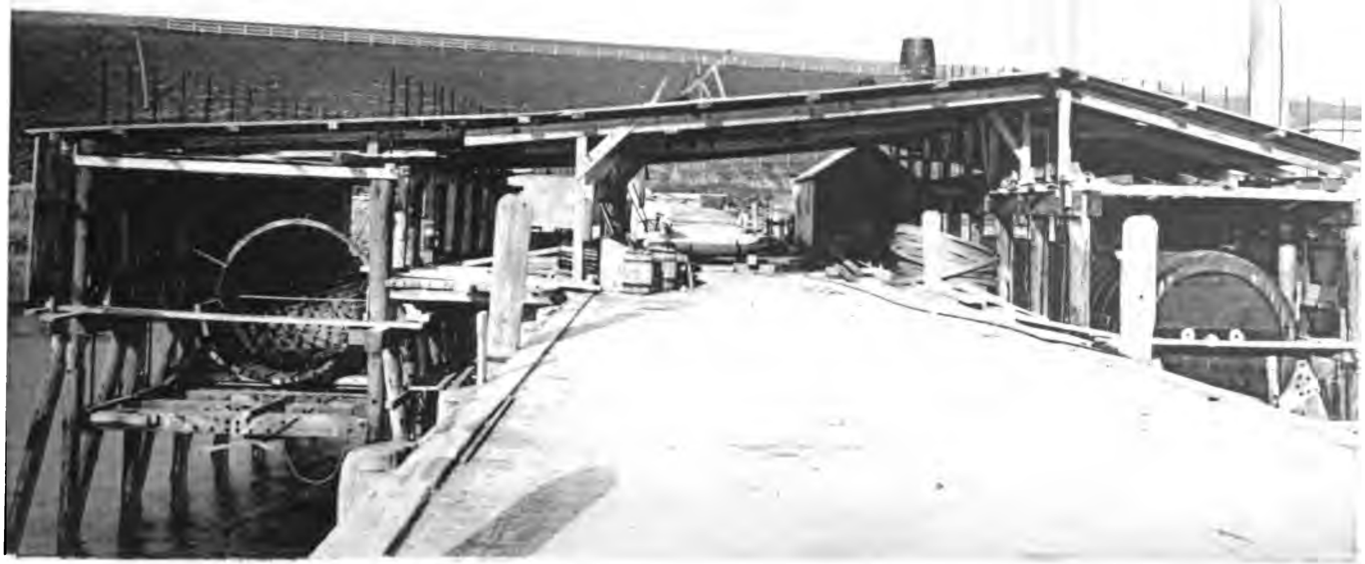
Maintenance and Operation of the Metropolitan System.

Force employed. — The 70 miles of metropolitan sewers are maintained by a permanent force of 25, including foreman, assistant foremen and laborers, with horses and carts.

They inspect at frequent intervals the inlets and sewer connections, flush and clean the sewers in special cases, remove ashes and screenings from the pumping stations, examine and clean sand-catchers as needed, and maintain a ferry at Shirley Gut. The total expenditure on account of this force for the year ending September 30, 1899, was $27,361.39.

Connections. — By the legislative acts the maintenance and operation of the metropolitan sewers devolve upon the Metropolitan Sewerage Commissioners. They entertain applications for connections with the sewers only from the governments of the various cities and towns. The duty of safeguarding the metropolitan sewers from the admission of offensive, explosive or otherwise objectionable matters is thus imposed upon the local bodies concerned. Applications for permission to make connections are signed by the city engineer or other properly authorized official. The design and construction of the necessary structures are subject to the approval of the commissioners. It is found necessary to adopt special regulations, dealing with the admission of various classes of trade refuse. From tanneries, all tan-press liquor is excluded, and beam-house drainage is specially screened. Solid wastes from abattoirs, etc., are intercepted at special screen man-holes. The admission of naphtha and other explosive matters is prohibited. These regulations apply to the public sewers of local authorities into which such refuse may be admitted, as well as to the special cases in which direct connections of manufactories, etc., with the metropolitan sewers have been sanctioned. The total number of connections, as on October 1, 1899, is shown by the following tables for each system, and by a further table for the metropolitan district as a whole. The tables include other statistics, indicating the extent to which the metropolitan sewers are used, to the above date.

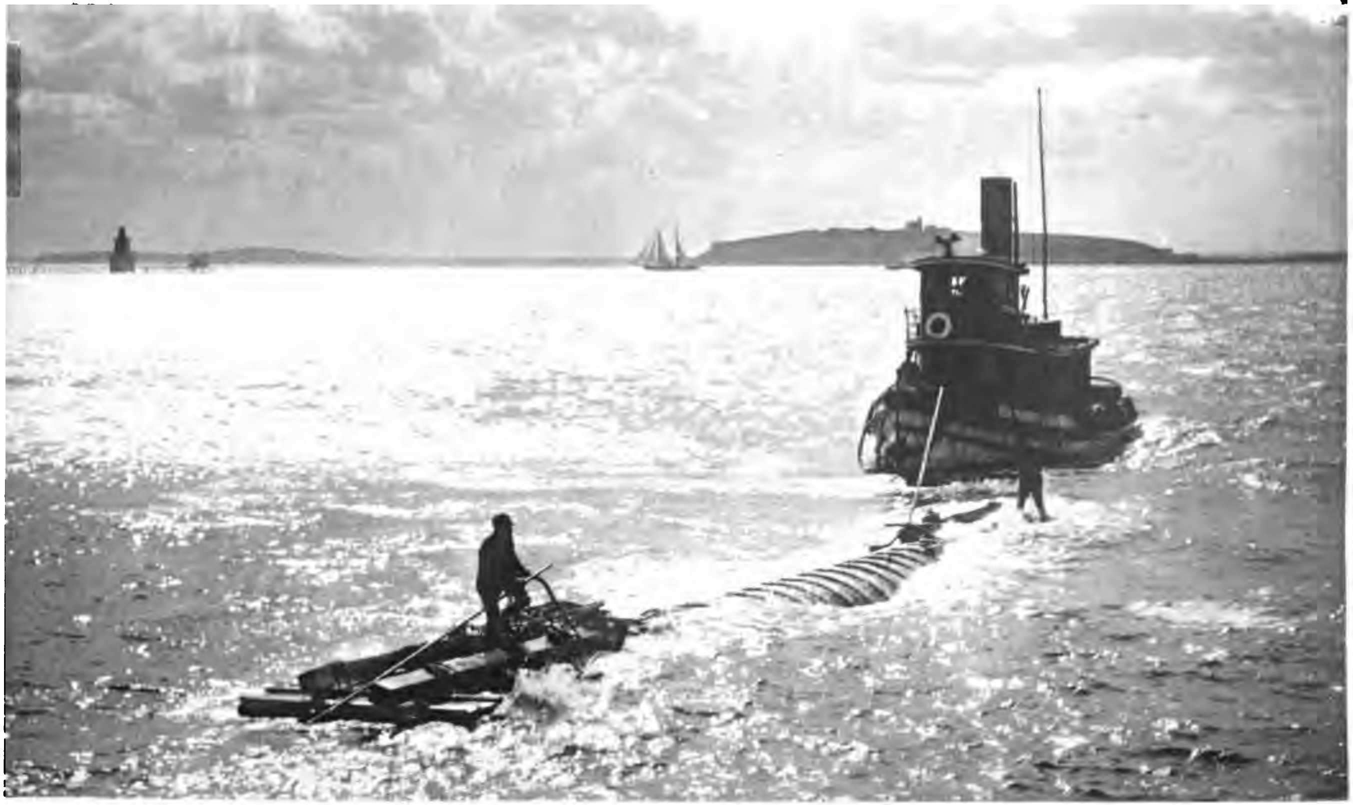
Plate 9.



Showing lagging and treenails. Pipe-section ready for lowering into the water.

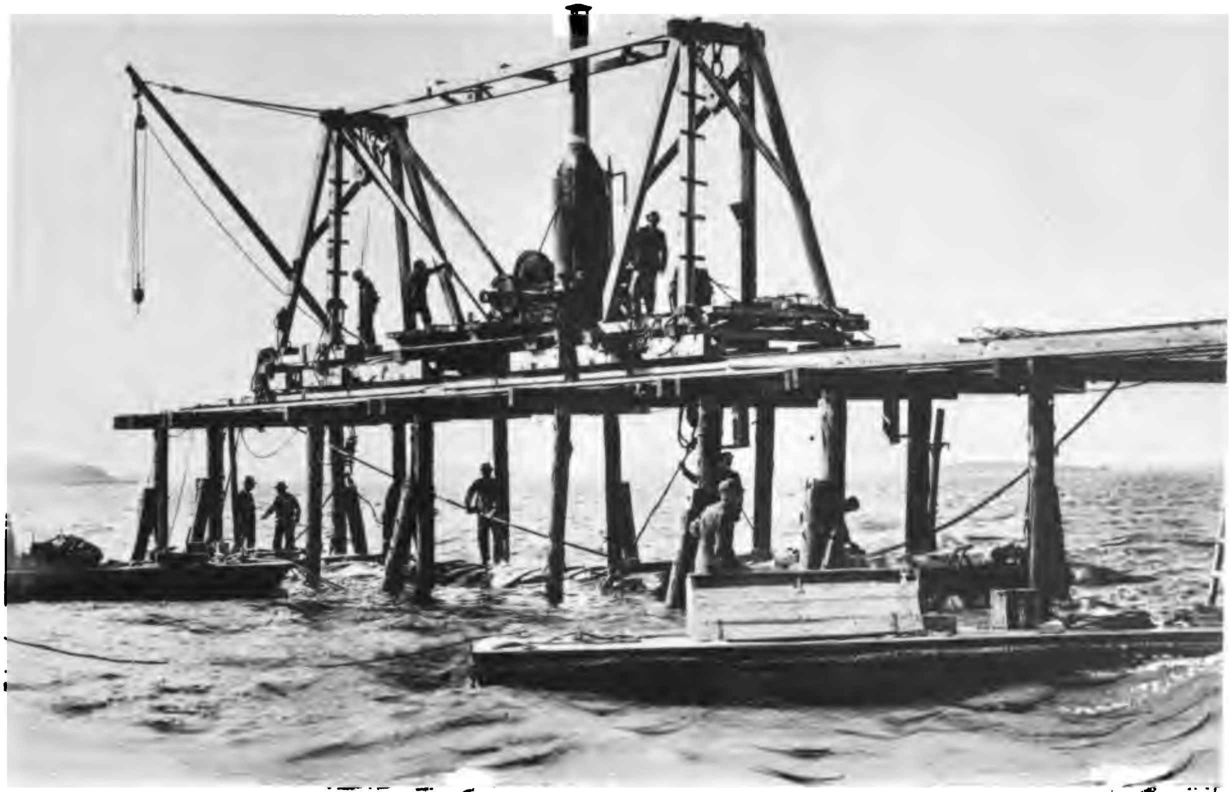
Deer Island Outfall: Cradles at Wharf.

Plate 10.



Deer Island Outfall: Towing one of the Pipe-sections from the cradle to the outfall.

Plate 11.



Deer Island Outfall: Pipe-section ready for lowering.

Charles River Valley System, October 1, 1899.

Table showing Cities and Towns delivering Sewage to this System; Number of Public and Special Connections; Approximate Miles of Sewer connected; Estimated Populations and Areas now contributing; Total Areas ultimately to contribute, and Present Populations on Such Areas; Ratios of Present Contributing Areas to Ultimate Areas, and Ratios of Populations now contributing to Present Total Populations.

Cities and Towns.	Public Connections.	Special Connections.	Miles of Local Sewer connected.	Separate or Combined.	Number of Connections with Local Sewers.	Estimated Number of Persons served by Each House-connection.*	Estimated Population now contributing Sewage.	Estimated Present Total Population.	Estimated Area now contributing Sewage.	Area ultimately to contribute Sewage.	Ratio of Contributing Population to Present Total Population.	Ratio of Contributing Area to Ultimate Area.
									Square Miles.	Square Miles.	Per Cent.	Per Cent.
Part of Boston (proper),	8	1	16.90	Sep. and com.	2,510	5.8	14,558	15,340	1.10	1.68	95.0	65.5
Boston (Brighton), .	10	3	47.19	Sep. and com.	2,200	5.8	12,760	18,600	3.02	4.27	68.5	70.7
Brookline, . . .	1	-	48.00	Combined.	2,215	6.6	14,619	19,410	2.91	4.84	75.3	60.1
Newton, ...	6	2	84.96	Separate.	3,770	5.3	19,981	31,720	5.95	13.60	63.0	43.8
Watertown, . . .	5	1	23.50	Separate.	1,175	6.4	7,520	9,000	1.61	4.04	83.6	39.9
Waltham, . . .	1	-	39.81	Separate.	2,696	6.2	19,850	23,050	2.40	13.63	86.1	17.6
Total, . . .	31	7	260.36	-	14,566	6.1	89,288	117,120	16.99	42.06	76.2	40.4

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* Estimated from assessors' statement of the number of houses in each city or town, and the population from census of 1895 extended to 1899.

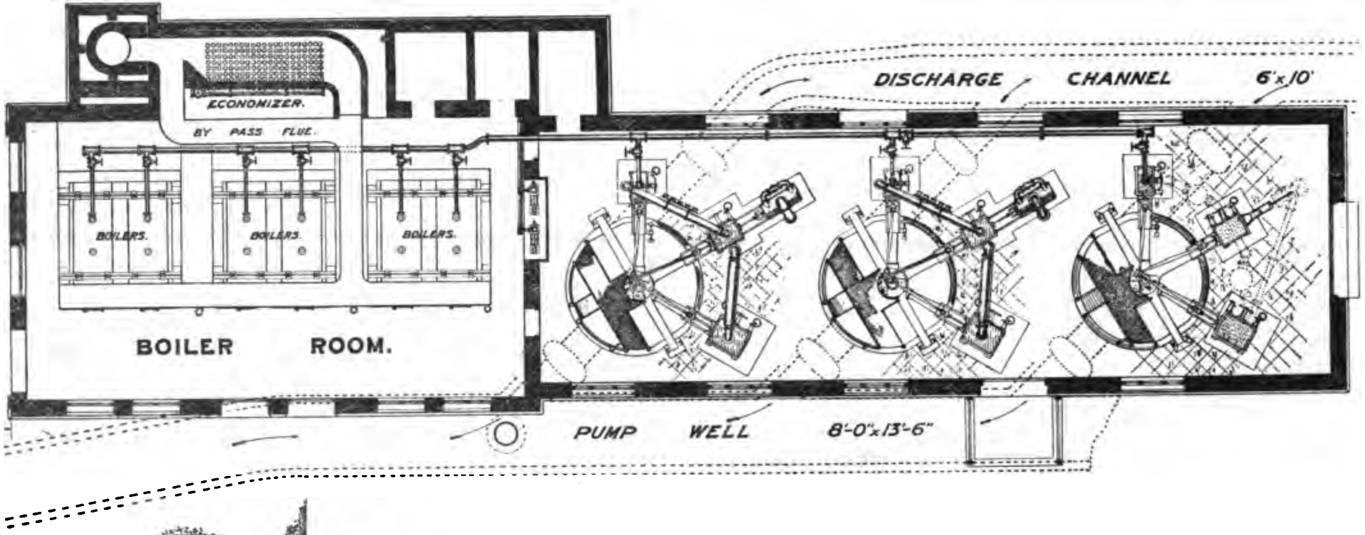
NORTH METROPOLITAN SYSTEM, OCTOBER 1, 1899.

Table showing Cities and Towns delivering Sewage to this System; Number of Public and Special Connections; Approximate Miles of Sewer connected; Estimated Populations and Areas now contributing; Total Areas ultimately to contribute, and Present Populations on Such Areas; Ratios of Present Contributing Areas to Ultimate Areas, and Ratios of Populations now contributing to Present Total Populations.

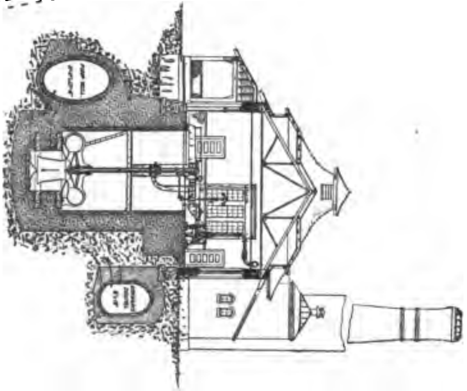
CITIES AND TOWNS.	Public Connections.	Special Connections.	Miles of Local Sewer connected.	Separate or Combined.	Number of Connections with Local Sewers.	Estimated Number of persons served per Each House-connection.*	Estimated Population now contributing Sewage.	Estimated Present Total Population.	Estimated Area now contributing Sewage.	Area ultimately to contribute Sewage.	Ratio of contributing Population to Present Total Population.	Ratio of Contributing Area to Ultimate Area.
									Square Miles.	Square Miles.	Per Cent.	Per Cent.
Boston (Deer Island), .	2	-	0.30	Separate.	-	-	1,400	1,400	-	-	-	-
Winthrop, ...	4	1	23.99	Separate.	1,358	3.9	5,296	5,560	1.51	1.61	95.0	93.8
Boston (East Boston), .	16	-	18.70	Sep. and com.	4,683	9.2	43,084	48,090	0.68	2.18	89.6	31.2
Chelsea, ...	3	2	1.85	Combined.	202	7.5	1,515	33,780	0.09	2.24	4.5	4.0
Everett, ...	3	1	13.82	Separate.	1,153	5.6	6,457	24,510	0.86	3.34	26.3	25.7
Malden, ...	20	83	41.30	Separate.	3,026	5.7	17,248	36,100	2.44	5.07	47.8	48.1
Melrose, ...	27	68	32.44	Separate.	1,600	4.6	7,360	14,880	1.46	3.73	49.5	39.1
Boston (Charlestown),	11	3	18.63	Sep. and com.	4,795	8.6	41,267	42,290	0.64	1.27	97.5	50.4
Cambridge, ...	19	1	108.18	Sep. and com.	13,276	6.7	88,949	91,270	4.83	6.11	97.3	79.0
Somerville, ...	8	1	70.90	Sep. and com.	10,905	5.9	60,431	61,800	3.24	3.96	97.8	81.8
Medford, ...	16	5	43.49	Separate.	2,002	5.5	11,011	18,170	2.31	8.35	60.6	27.7
Winchester, ...	8	2	17.00	Separate.	466	5.3	2,470	7,150	0.88	5.95	34.5	14.8
Woburn, ...	3	1	13.97	Separate.	741	5.9	4,372	15,550	0.88	12.70	28.1	6.9
Stoneham, ...	2	-	10.20	Separate.	211	4.7	992	6,770	0.55	5.50	14.7	10.0
Arlington, ...	27	42	16.52	Separate.	445	5.5	3,000	7,780	1.55	5.20	38.6	29.8
Belmont, ...	1	-	5.60	Separate.	145	6.4	1,328	3,770	0.74	4.66	35.2	15.9
Wakefield, ...	-	-	-	-	-	-	-	760	-	0.95	-	-
Lexington, ...	-	-	-	-	-	-	-	2,730	-	5.11	-	-
Total, ...	170	210	436.89	-	45,008	6.6	296,180	422,360	22.66	77.93	70.1	29.1

* Estimated from assessors' statement of the number of houses in each city or town, and the population from census of 1895 extended to 1899.

Plate 12.



PLAN OF PUMPING STATION,
DEER ISLAND.



SECTION THROUGH PUMP,
DEER ISLAND STATION.

NEPONSET VALLEY SYSTEM, OCTOBER 1, 1899.

Table showing Cities and Towns delivering Sewage to this System; Number of Public and Special Connections; Approximate Miles of Sewer connected; Estimated Populations and Areas now contributing; Total Areas ultimately to contribute, and Present Populations on Such Areas; Ratios of Present Contributing Areas to Ultimate Areas, and Ratios of Populations now contributing to Present Total Populations.

CITIES AND TOWNS.	Public Connections.	Special Connections.	Miles of Local Sewer connected.	Separate or Combined.	Number of Connections with Local Sewers.	Estimated Number of Persons served by Each House-connection.*	Estimated Population now contributing Sewage.	Estimated Present Total Population.	Estimated Area now contributing Sewage.	Area Ultimately to contribute Sewage.	Ratio of Contributing Population to Present Total Population.	Ratio of Contributing Area to Ultimate Area.
									Square Miles.	Square Miles.	Per Cent.	Per Cent.
Boston (Dorchester), .	6	-	11.73	Sep. and com.	901	6.3	5,676	11,300	0.76	2.59	50.0	29.0
Milton, ...	3	-	2.96	Sep. and com.	47	5.3	249	3,850	0.15	12.59	6.45	1.2
Hyde Park, . . .	10	-	12.18	Separate.	287	7.7	2,209	13,646	0.71	4.57	16.2	15.6
Dedham, ...	-	-	-	-	-	-	-	7,200	-	14.10	-	-
Boston (West Roxbury),	2	1	2.45	Separate.	56	6.4	558	1,900	0.17	4.02	34.0	4.2
Brookline, ...	-	-	-	-	-	-	-	400	-	1.97	-	-
Newton, ...	-	-	-	-	-	-	-	400	-	4.43	-	-
Total, ...	21	1	29.32	-	1,291	6.7	8,692	38,696	1.79	44.27	22.5	4.05

* Estimated by local engineers.

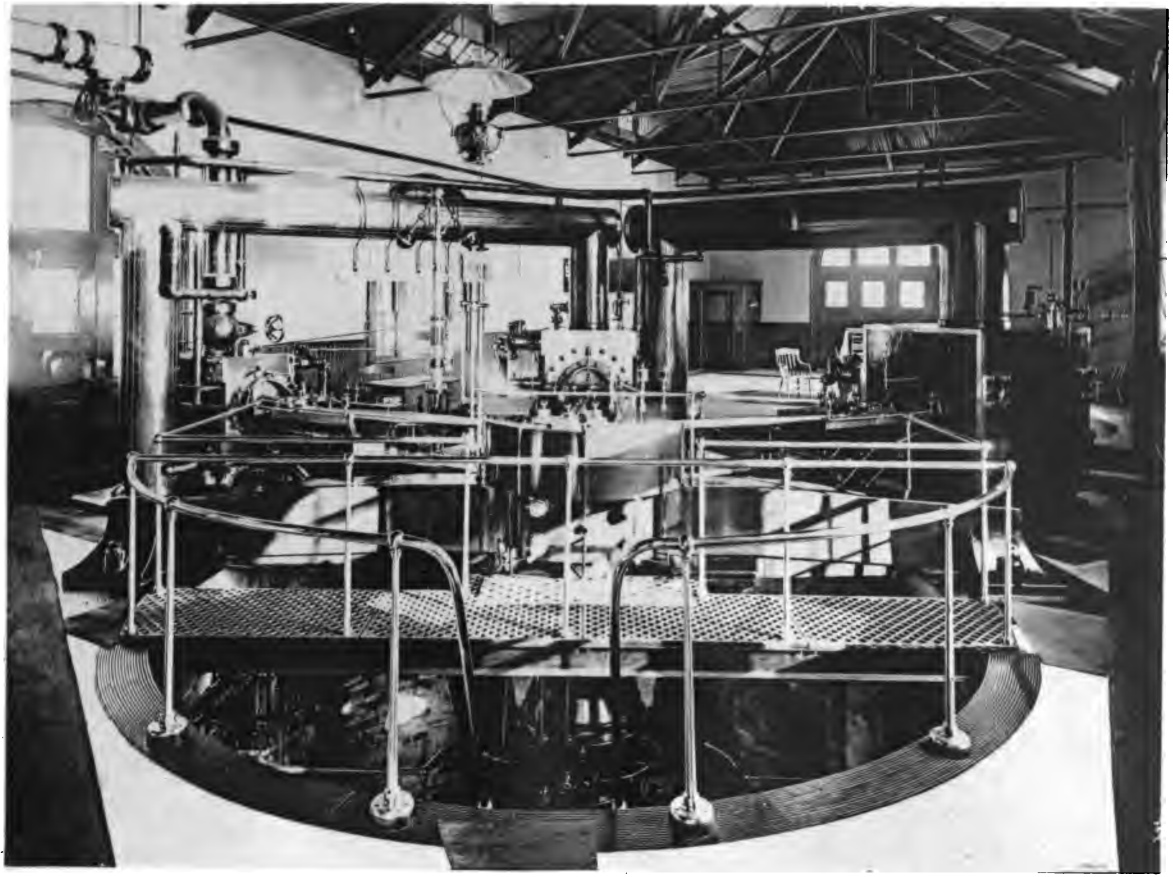
WHOLE METROPOLITAN SYSTEM, OCTOBER 1, 1899.

Table showing Areas delivering Sewage to the entire System, exclusive of added High-level Area; Number of Public and Special Connections; Approximate Miles of Sewer connected; Estimated Populations and Areas now contributing; Total Areas ultimately to contribute, and Present Populations on Such Areas; Ratios of Present Contributing Areas to Ultimate Areas, and Ratios of Populations now contributing to Present Total Populations.

SYSTEM.	Public Connections.	Special Connections.	Miles of Local Sewer connected.	Separate or Combined.	Number of Connections with Local Sewers.	Estimated Number of Persons served by Each House-connection.	Estimated Population now contributing Sewage.	Estimated Present Total Population.	Estimated Area now contributing Sewage.	Area ultimately to contribute Sewage.	Ratio of Contributing Population to Present Total Population.	Ratio of Contributing Area to Ultimate Area.
									Square Miles.	Square Miles.	Per Cent.	Per Cent.
Charles River Valley, .	31	7	260.36	Sep. and com.	14,566	6.1	89,288	117,120	16.99	42.06	76.2	40.4
North Metropolitan, .	170	210	436.89	Sep. and com.	45,008	6.6	296,180	422,360	22.66	77.93	70.1	29.1
Neponset River Valley,	21	1	29.32	Sep. and com.	1,291	6.7	8,692	38,696	1.79	44.27	22.5	4.05
Total, . . .	222	218*	726.57	-	60,865	6.5	394,160	578,176	41.44	164.26	68.2	25.2

* The special connections consist largely of house-drains on local sewers, purchased by the commissioners for use as main sewers.

Plate 13.



Interior of Deer Island Pumping Station.

It appears from these tables that on October 1, 1899, there were 578,176 persons residing in the three metropolitan districts already provided for by the commission. Of these, about 394,160 persons, representing 68.2 per cent. of the whole, were on that date contributing sewage to the metropolitan sewers, through a total length of 726 miles of local sewers owned by the several cities and towns, these sewers being connected with the metropolitan system by means of 222 public and 218 special connections.

Screens and Siphons. — Before being admitted to the pumps, the sewage at each pumping station passes through substantial wrought-iron cages, provided in duplicate. They are hung in shafts extending from the sewer invert to about the level of the engine-room floor, and operated by special machinery. A total of about 1,000 cubic yards of material is annually intercepted at the four stations, being at the rate of about 1.6 cubic feet to each million gallons of sewage delivered at the outfall. Practically no deposits are removed from the main sewers or from the siphons, indicating that the velocities maintained in the sewers and siphons are sufficient to carry the suspended matters to the outfall. Careful observations of loss of head at all the siphons are made at frequent intervals; these show that, after five years' service, no appreciable deposits exist within the siphons.

Velocity of Sewage Flow. — The time occupied by sewage in passing through the north metropolitan system to the outlet at Deer Island from various points on the area has been studied by means of surface floats. On the dates of observations the sewers had a depth of flow ranging from 13 to 36 per cent. of their vertical diameters. Taking 80 per cent. of the observed surface velocity as the mean velocity of the section, the observations do not sensibly disagree with results obtained from calculations based upon theoretical velocities. It appears that tannery refuse from Woburn, 17 miles distant from the Deer Island outlet, is delivered at the latter point in about fourteen hours after its discharge into the metropolitan sewer. Effluent from the large pork-packing establishments in Somerville is delivered in about seven hours, the distance travelled being over 10 miles.

Pumping Stations. — The force at the large pumping stations (Deer Island, East Boston and Charlestown) consists of three engineers, three firemen, four screen-men and one relief man for each station, working in shifts of 9 hours.

Pumping Records. — The three following tables show the respective pumping records of the large stations for the year ending September 30, 1899 : —

Table of Approximate Quantities, Lifts and Duties at the Deer Island Pumping Station of the North Metropolitan System.

MONTHS.	Total Pumpage (Gallons).	Average per Day (Gallons).	Minimum Day (Gallons).	Maximum Day (Gallons).	Average Lift (Feet).	Average Duty (Million ft.-lbs. per 100 lbs. Coal).
1898-99.						
October, .	1,371,000,000	44,200,000	34,600,000	74,700,000	9.99	57,700,000
November, .	1,438,500,000	47,900,000	38,600,000	67,700,000	10.66	59,600,000
December, .	1,626,400,000	52,500,000	43,800,000	75,900,000	11.06	56,600,000
January, .	1,832,300,000	59,100,000	45,900,000	85,700,000	11.51	59,500,000
February, .	1,576,200,000	56,300,000	42,400,000	85,700,000	11.53	53,700,000
March, . .	2,120,700,000	68,400,000	51,000,000	86,800,000	12.46	63,600,000
April, . .	1,477,500,000	49,200,000	38,100,000	75,100,000	11.33	55,300,000
May, . .	1,239,600,000	40,000,000	35,500,000	44,800,000	12.48	53,000,000
June, . .	1,142,600,000	38,100,000	32,300,000	59,100,000	12.33	46,300,000
July, . .	1,171,700,000	37,800,000	30,600,000	56,300,000	12.00	48,500,000
August, .	1,175,700,000	38,200,000	31,000,000	47,300,000	11.20	55,800,000
September, .	1,184,000,000	39,500,000	27,900,000	67,100,000	11.25	57,700,000
Total, .	17,356,200,000	-	-	-	-	-
Average,	-	47,600,000	37,600,000	68,800,000	11.50	55,600,000

Table of Approximate Quantities, Lifts and Duties at the East Boston Pumping Station of the North Metropolitan System.

MONTHS.	Total Pumpage (Gallons).	Average per Day (Gallons).	Minimum Day (Gallons).	Maximum Day (Gallons).	Average Lift (Feet).	Average Duty (Million ft. lbs. per 100 lbs. Coal).
1898-99.						
October, .	1,292,500,000	41,700,000	30,000,000	68,100,000	15.20	53,800,000
November, .	1,378,200,000	45,900,000	34,900,000	62,800,000	15.49	54,300,000
December, .	1,610,100,000	51,900,000	41,300,000	75,300,000	15.66	57,600,000
January, .	1,805,900,000	58,300,000	45,200,000	77,500,000	15.79	58,300,000
February, .	1,522,700,000	54,400,000	41,000,000	76,600,000	15.47	59,500,000
March, . .	2,065,600,000	66,600,000	47,000,000	82,800,000	15.79	56,500,000
April, . .	1,412,800,000	47,100,000	36,800,000	68,700,000	17.44	44,700,000
May, . .	1,168,500,000	37,700,000	32,300,000	46,400,000	14.93	52,800,000
June, . .	1,197,800,000	39,900,000	32,500,000	48,800,000	14.80	55,500,000
July, . .	1,144,100,000	36,900,000	31,700,000	51,800,000	15.02	51,200,000
August, .	1,165,000,000	37,500,000	34,000,000	47,300,000	14.48	56,800,000
September, .	1,115,400,000	37,200,000	27,800,000	59,500,000	14.78	53,800,000
Total, .	16,878,600,000	-	-	-	-	-
Average,	-	46,200,000	36,200,000	63,800,000	15.40	54,600,000

Table of Approximate Quantities, Lifts and Duties at the Charlestown Pumping Station of the North Metropolitan System.

MONTHS.	Total Pumpage (Gallons).	Average per Day (Gallons).	Minimum Day (Gallons).	Maximum Day (Gallons).	Average Lift (Feet).	Average Duty (Million ft.-lbs. per 100 lbs. Coal).
1898-99.						
October,	780,000,000	25,200,000	19,100,000	39,200,000	7.81	59,400,000
November,	786,400,000	26,200,000	17,100,000	37,700,000	7.87	60,700,000
December,	907,300,000	29,300,000	23,300,000	43,900,000	8.33	64,500,000
January,	1,027,600,000	33,100,000	24,300,000	46,900,000	8.39	64,300,000
February,	914,000,000	32,600,000	25,400,000	49,600,000	8.75	66,500,000
March,	1,181,000,000	38,100,000	25,600,000	48,900,000	9.08	66,700,000
April,	789,800,000	26,300,000	20,100,000	39,500,000	8.83	55,500,000
May,	753,700,000	24,300,000	21,600,000	29,800,000	8.65	56,400,000
June,	803,200,000	26,800,000	21,000,000	35,200,000	8.64	65,500,000
July,	761,000,000	24,500,000	20,400,000	32,200,000	8.93	56,500,000
August,	747,300,000	24,100,000	16,900,000	30,600,000	8.89	53,300,000
September,	762,600,000	25,400,000	17,900,000	36,000,000	8.90	60,000,000
Total,	10,213,900,000	-	-	-	-	-
Average,	-	28,000,000	21,000,000	39,100,000	8.60	60,800,000

Cost of Pumping. — The average cost of pumping at the three large stations during the same period is given in detail in the following tables: —

Average Cost per Million Foot-gallons for Pumping at the Deer Island Station, Year ending September 30, 1899.

Annual Volume (17,356 Million Gallons) × Lift (11.5 Feet) = 199,594 Million Foot-gallons.

ITEMS.	Cost.	Cost per Million Foot-gallons.
Labor,	$7,603 69	$0.03810
Coal,	3,964 37	.01986
Oil,	303 54	.00152
Waste,	30 82	.00015
Water,	882 60	.00442
Packing,	99 01	.00050
Miscellaneous supplies and renewals,	613 43	.00307
Total,	$13,497 46	$0.06762

Average Cost per Million Foot-gallons for Pumping at the East Boston Station, Year ending September 30, 1899.

Annual Volume (16,879 Million Gallons) × Lift (15.4 Feet) = 259,936 Million Foot-gallons.

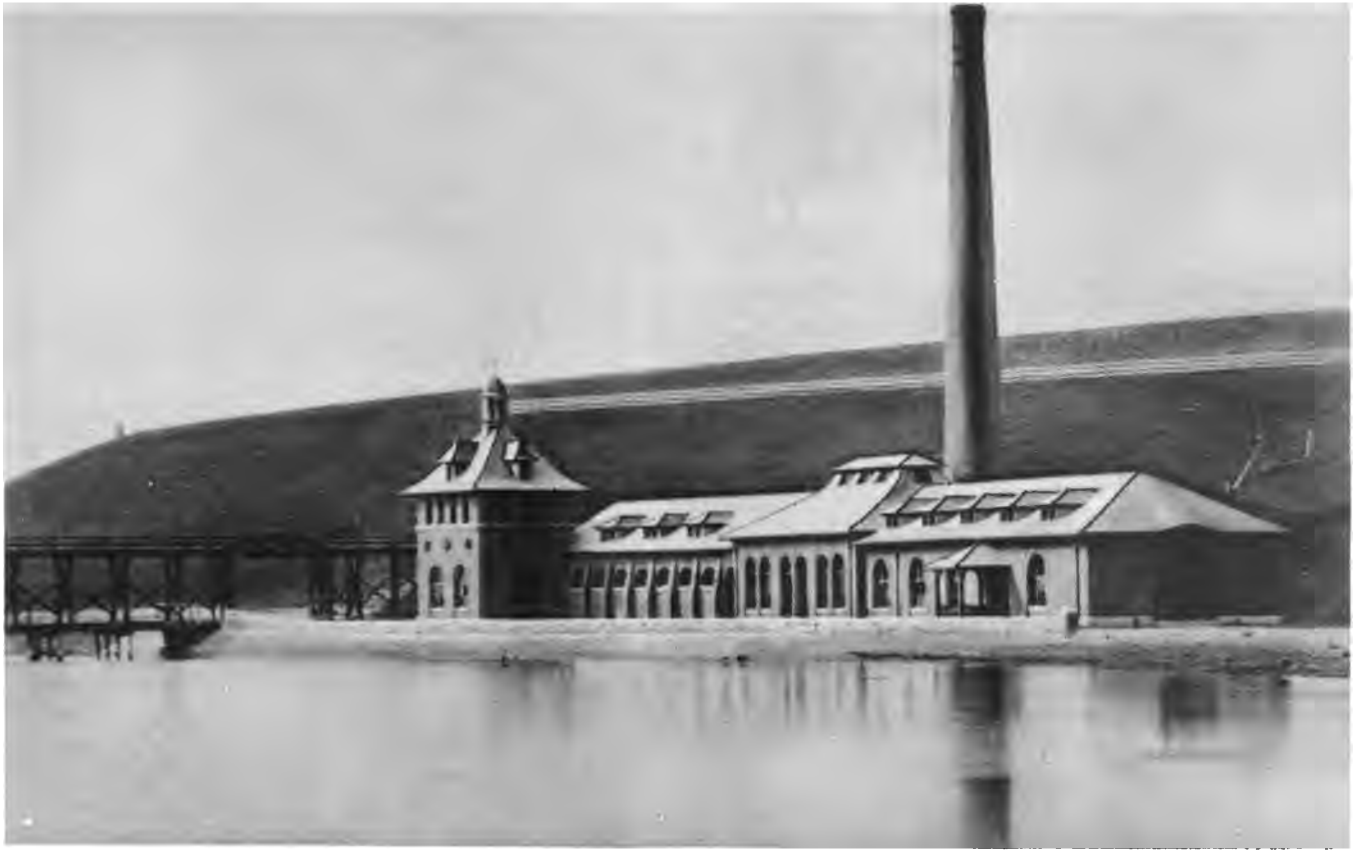
ITEMS.	Cost.	Cost per Million Foot-gallons.
Labor,	$7,776 69	$0.02992
Coal,	5,964 83	.02294
Oil,	231 69	.00089
Waste,	41 80	.00016
Water,	940 80	.00362
Packing,	30 02	.00012
Miscellaneous supplies and renewals,	541 05	.00208
Total,	$15,526 88	$0.05973

Average Cost per Million Foot-gallons for Pumping at the Charlestown Station, Year ending September 30, 1899.

Annual Volume (10,214 Million Gallons) × Lift (8.6 feet) = 87,840 Million Foot-gallons.

ITEMS.	Cost.	Cost per Million Foot-gallons.
Labor,	$7,292 57	$0.08302
Coal,	1,994 18	.02270
Oil,	344 95	.00393
Waste,	45 48	.00052
Water,	327 25	.00373
Packing,	100 00	.00114
Miscellaneous supplies and renewals,	274 35	.00312
Total,	$10,378 78	$0.11816

Plate 14.



Exterior View, Deer Island Pumping Station.

M

METROPOLITAN SEWERAGE COMMISSION AND ITS OFFICERS FROM 1889 TO 1899.

Commissioners.

From 1889 to 1892. — HOSEA KINGMAN.
TILLY HAYNES.
ROBERT T. DAVIS.
From 1892 to 1895. — HOSEA KINGMAN.
TILLY HAYNES.
HARVEY N. COLLISON.
From 1895 to 1896. — HOSEA KINGMAN.
TILLY HAYNES.
ALBERT F. NOYES.
From 1896 to ——. — HOSEA KINGMAN.
TILLY HAYNES.
GEORGE A. KIMBALL.

Clerks of Commission.

From 1889 to 1898. — EDWARD P. FISK.
From 1898 to ——. — HERBERT E. BRAYTON.

Chief Engineers.

From 1889 to 1895. — HOWARD A. CARSON.
From 1895 to ——. — WILLIAM M. BROWN, Jr.

The following publications, among others, have been used in the compilation of this memoir: —

The sewerage of Boston. Report of the 1875 commission, consisting of E. S. Chesborough, C.E., Moses Lane, C.E., and Charles F. Folsom, M.D. (City Doc. No. 3, 1876.)

Report of the joint special committee on the improved sewerage of Boston, July, 1877, including preliminary reports by Joseph P. Davis, City Engineer, and Eliot C. Clarke, Principal Assistant Engineer. (City Doc. No. 70, 1877.)

Report of the Metropolitan Drainage Commission, consisting of E. S. Chesborough, Henry P. Walcott, Charles F. Folsom, A. W. Boardman and Azel Ames, Jr. (House Doc. No. 4, 1882.)

Main drainage works of the city of Boston, by Eliot C. Clarke, Principal Assistant Engineer. (1885.)

Report of the Massachusetts Drainage Commission, consisting of John Q. Adams, Solomon B. Stebbins, Edmund W. Converse, Edmund D. Hayden and Leverett S. Tuckerman, including reports by Joseph P. Davis and Rudolph Hering, Consulting Engineers, and Eliot C. Clarke, Chief Engineer. (1886.)

Report of the State Board of Health, consisting of Henry P. Walcott, Elijah U. Jones, Julius H. Appleton, Thornton K. Lothrop, Frank W. Draper, Hiram F. Mills and Theodore C. Bates, upon the sewerage of the Mystic and Charles River valleys, including reports by Joseph P. Davis, Consulting Engineer, F. P. Stearns, Chief Engineer of the Board, Howard A. Carson, C.E., Charles H. Swan, C.E., and Fred Brooks, C.E., together with chapter 439, Acts of 1889. (Senate Doc. No. 2, 1889.)

The metropolitan sewerage system, by Howard A. Carson, engineer metropolitan sewerage system. Paper in "Technology Quarterly," Boston, December, 1893.

Annual reports of the Board of Metropolitan Sewerage Commissioners, numbers 1 to 11 inclusive, to October 1, 1899.

Special report of the Metropolitan Sewerage Commissioners upon a high-level gravity sewer for the relief of the Charles and Neponset River valleys, including reports by Joseph P. Davis, Consulting Engineer, Wm. M. Brown, Jr., Chief Engineer to the Commissioners, and H. W. Clark, Chemist to the State Board of Health. (Resolves of 1898, chapter 4, January, 1899.)

Annual reports of the street department of the city of Boston, particularly those for 1896, 1897 and 1898.

The following table is submitted for the convenience of readers who are chiefly familiar with the metric system : —

1 inch . . . . = 1/12 foot.
25.4 millimetres.
1 foot . . . . = 0.3048 metre.
1 cubic foot . . = 0.0283 cubic metre.
28.3 litres.
1 cubic yard . . = 27 cubic feet.
0.7645 cubic metre.
1 mile . . . . = 5,280 feet.
1.6093 kilometre.
1 acre . . . . = 0.4047 hectares.
1 square mile . . = 640 acres.
259 hectares.
1 United States gallon = 231 cubic inches.
0.1337 cubic foot.
0.833 Imperial gallon (British).
3.785 litres.
1 pound . . . = 0.4536 kilogramme.
1 ton . . . . = 2,240 pounds.
1,016 kilogrammes.
1 dollar . . . = 100 cents.
francs 5.18.
£ 0.205.
Marks 4.17.

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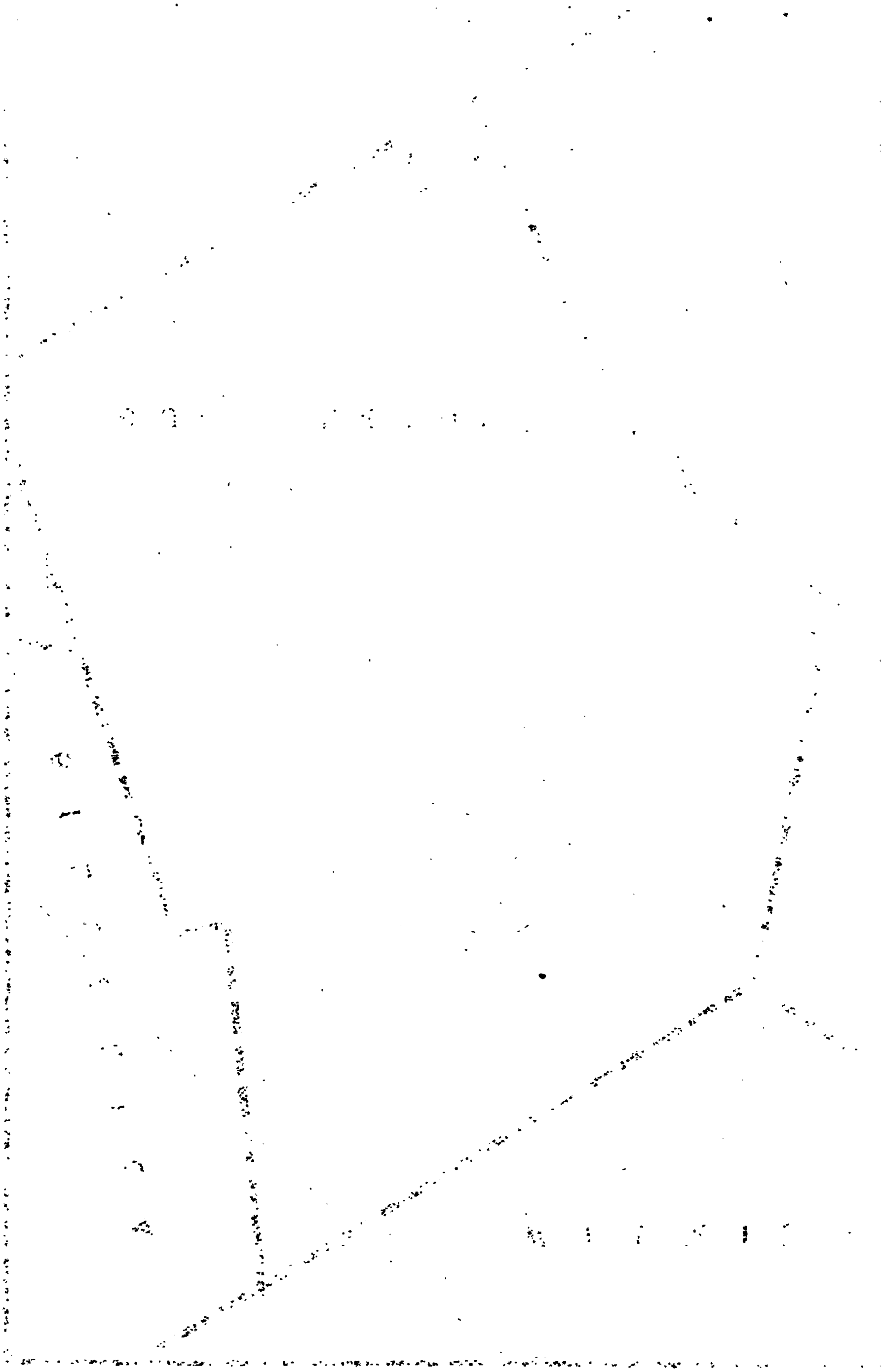

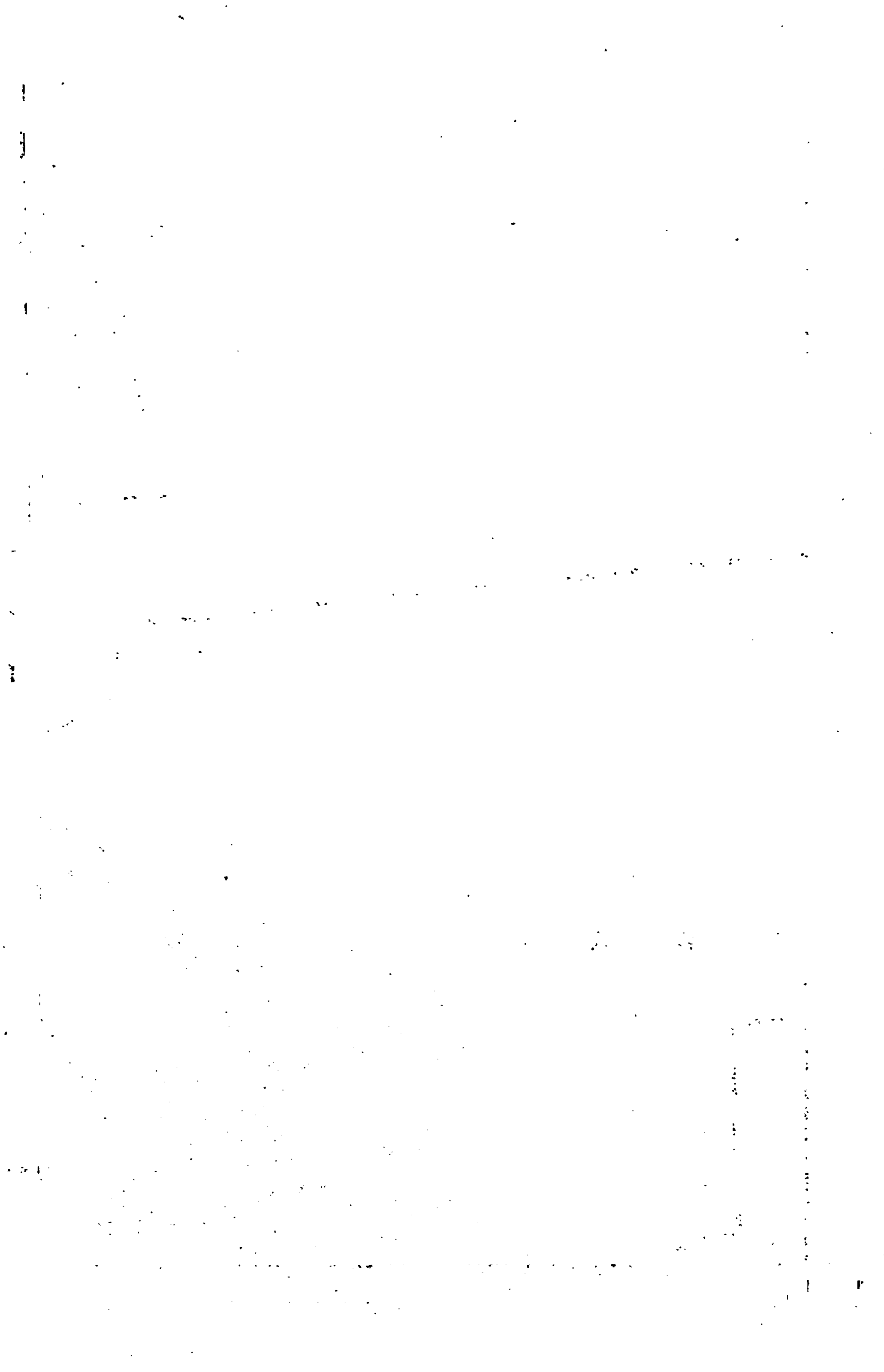

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